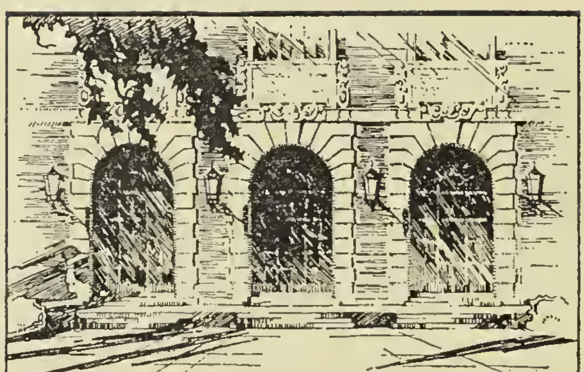

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WASHINGTON, D. C.

WASHINGTON, D. C., *April*, 1890.

NINTH ANNUAL REPORT

OF THE

# UNITED STATES GEOLOGICAL SURVEY

TO THE

SECRETARY OF THE INTERIOR

1887-'88

BY

J. W. POWELL
DIRECTOR

WASHINGTON
GOVERNMENT PRINTING OFFICE
1889

# NINTH ANNUAL REPORT

OF THE

# DIRECTOR

OF THE

# UNITED STATES GEOLOGICAL SURVEY.

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# LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
*Washington, D. C., September* 6, 1888.

SIR: I have the honor to transmit herewith a report of the operations of the Geological Survey for the fiscal year ending June 30, 1888.

Please accept my earnest thanks for the kind and careful consideration you have given to the work under my charge.

I am, with respect, your obedient servant,

J. W. POWELL,
*Director.*

Hon. WM. F. VILAS,
*Secretary of the Interior.*

# NINTH ANNUAL REPORT OF THE UNITED STATES GEOLOGICAL SURVEY.

By J. W. Powell, Director.

## PROGRESS IN TOPOGRAPHIC WORK.

During the past year topographic surveys have been carried forward under the charge of Mr. Henry Gannett in accordance with the general plan developed in previous reports, and satisfactory progress has been made. The area surveyed was 52,062 square miles. The distribution of the work done is shown graphically in Pl. I, in the pocket at the end of the volume. The following table exhibits in detail, by States, the present condition of the work, together with that executed during the past fiscal year:

*Table showing the present condition of topographic surveys and the areas surveyed in 1887–'88, by States and Territories.*

| State. | Total area of State. | Area surveyed to date. | Area surveyed in 1887–'8. | Scale. | Contour interval. |
|---|---|---|---|---|---|
| | *Sq. miles.* | *Sq. miles.* | *Sq. miles.* | | *Feet.* |
| Alabama | 52,250 | 9,320 | 3,000 | 1 : 125,000 | 100 |
| Arizona | 113,020 | 41,000 | ............ | 1 : 250,000 | 200 and 250 |
| Arkansas | 53,850 | 4,000 | 4,000 | 1 : 125,000 | 50 |
| California | 158,360 | 23,000 | 1,436 | 1 : 250,000 | 100 and 200 |
| Colorado | 103,925 | 2,500 | ............ | 1 : 125,000 | 100 |
| Connecticut | 4,990 | 150 | ............ | 1 : 62,500 | 20 |
| District of Columbia | 70 | 70 | 70 | 1 : 62,500 | 20 |
| Georgia | 59,475 | 9,030 | 2,100 | 1 : 125,000 | 100 |
| Iowa | 56,025 | 950 | 950 | 1 : 62,500 | 20 |
| Kansas | 82,080 | 28,000 | 1,000 | 1 : 125,000 | 50 |

*Table showing the present condition of topographic surveys and the areas surveyed in* 1887–'88, *etc.*—Continued.

| State. | Total area of State. | Area surveyed to date. | Area surveyed in 1887–'8. | Scale. | Contour interval. |
|---|---|---|---|---|---|
| | *Sq. miles.* | *Sq. miles.* | *Sq. miles.* | | *Feet.* |
| Kentucky | 40,400 | 6,270 | 1,400 | 1: 125,000 | 100 |
| Maryland | 12,210 | 3,080 | 900 | 1: 125,000 | 20, 50, 100 |
| Massachusetts | 8,315 | 8,315 | 2,350 | 1: 62,500 | 20 |
| Missouri | 69,415 | 26,000 | 7,900 | 1: 125,000 | 50 |
| Montana | 146,080 | 6,000 | 3,010 | 1: 250,000 | 200 |
| Nevada | 110,700 | 14,000 | ........... | 1: 250,000 | 200 and 250 |
| New Hampshire | 9,305 | 100 | ........... | 1: 62,500 | ........... |
| New Jersey | 7,815 | 7,815 | ........... | 1: 62,500 | 10 and 20 |
| New Mexico | 122,580 | 15,000 | 7,200 | 1: 250,000 | 200 |
| North Carolina | 52,250 | 9,900 | 1,300 | 1: 125,000 | 100 |
| Oregon | 96,030 | 8,000 | 3,327 | 1: 250,000 | 200 |
| Rhode Island | 1,250 | 250 | 144 | 1: 62,500 | 20 |
| South Carolina | 30,570 | 2,[illegible]00 | ........... | 1: 125,000 | 100 |
| Tennessee | 42,050 | 12,615 | ........... | 1: 125,000 | 100 |
| Texas | 265,780 | 20,000 | 4,650 | 1: 125,000 | 50 |
| Utah | 84,970 | 6,000 | ........... | 1: 250,000 | 250 |
| Vermont | 9,565 | 100 | ........... | 1: 62,500 | 20 |
| Virginia | 42,450 | 22,225 | 6,025 | 1: 125,000<br>1: 62,500 | 50 and 100<br>20 |
| West Virginia | 24,780 | 15,150 | 1,800 | 1: 125,000 | 100 |
| Wisconsin | 56,040 | 1,000 | 136 | 1: 62,500 | 20 |
| Wyoming, including Yellowstone National Park | 97,890 | 4,000 | ........... | 1: 125,000 | 100 |
| Total | ........... | 306,140 | ........... | ........... | ........... |

The survey of Massachusetts, which was undertaken in 1884 in cooperation with the State authorities, has been completed, and the work has met with the approval of the commissioners representing the State. The maps have been drawn and a number of them have been engraved. The small map of Massachusetts, upon a scale of 1: 300,000, reduced from the atlas sheets in 100 feet contours, has been substantially completed. In Maryland an atlas-sheet area, embracing Baltimore and its suburbs, has been surveyed on the mile scale for publication. In the southern Appalachian region work has been extended

both in the mountains and in the comparatively level country upon the east and south. Work has been commenced in Arkansas, Iowa, and Wisconsin, and has been extended northward in Texas. In the Far West the survey of the plateau region of New Mexico, of the Sierra Nevada in California, of the Cascade Range in Oregon, and of the Rocky Mountains of Montana, has been considerably extended.

The improvements in instruments and methods of work have kept pace with the extension of surveys. The recognized object of the work being the production of a topographic map solely, it has been found that graphic methods of work are not only the most economical and rapid, but that they yield the best results in quality; hence the development of method has tended in the direction of the use of the plane table for all surveying processes, and this has been carried out as rapidly and as far as the instruments could be adapted to the required purposes.

The engraving of the maps has gone forward during the year with a fair degree of rapidity, but not as rapidly as is required to keep pace with their preparation. At the date of my last report 120 sheets had been engraved, and a small edition (250 copies) of each sheet had been printed for the use of the office and to supply pressing demands. During the year contracts for engraving 100 sheets have been made by the Public Printer with Messrs. Bien & Co., of New York. The following table shows the numbers, distribution, and areas of the 46 sheets thus far engraved under the contract:

*Table showing number, distribution, etc., of the atlas sheets engraved to the 30th of June,* 1888.

| State or Territory. | Wholly in State. | Partly in State. | Scale. | Contour interval (feet). | Approximate area (square miles). |
|---|---|---|---|---|---|
| Alabama | 3 | 3 | 1 : 125,000 | 100 | 4,200 |
| Arizona | 14 | 2 | 1 : 250,000 | 200 and 250 | 58,000 |
| California | 8 | 1 | 1 : 125,000 | 100 and 200 | 25,000 |
| District of Columbia | ........ | 2 | 1 : 62,500 | 20 | 70 |
| Georgia | 1 | 4 | 1 : 125,000 | 100 | 3,800 |
| Kansas | 10 | 4 | 1 : 125,000 | 50 | 13,000 |
| Kentucky | 1 | 6 | 1 : 125,000 | 100 | 4,300 |

*Table showing number, distribution, etc., of the atlas sheets engraved to the 30th of June,* 1888—Continued.

| State or Territory. | Wholly in State. | Partly in State. | Scale. | Contour interval (feet). | Approximate area (square miles). |
|---|---|---|---|---|---|
| Maryland | ........ | 4 | 1 : 62,500<br>1 : 125,000 | 20 and 100 | 800 |
| Massachusetts | 6 | 1 | 1 : 62,500 | 20 and 40 | 1,500 |
| Missouri | 16 | 4 | 1 : 125,000 | 50 | 17,000 |
| Montana | 4 | ........ | 1 : 250,000 | 200 | 13,300 |
| Nevada | 4 | 3 | 1 : 250,000 | 200 | 23,500 |
| New Jersey | 22 | ........ | 1 : 62,500 | 10 and 20 | 5,000 |
| New Mexico | 2 | ........ | 1 : 250,000 | 200 | 8,000 |
| North Carolina | 1 | 7 | 1 : 125,000 | 100 | 3,800 |
| Rhode Island | ........ | 1 | 1 : 62,500 | 20 | 30 |
| South Carolina | ........ | 1 | 1 : 125,000 | 100 | 200 |
| Tennessee | 5 | 12 | 1 : 125,000 | 100 | 10,600 |
| Texas | 12 | ........ | 1 : 125,000 | 50 | 12,000 |
| Utah | 17 | 1 | 1 : 250,000 | 250 | 65,000 |
| Virginia | ........ | 14 | 1 : 125,000 | 100 | 5,700 |
| West Virginia | 3 | 7 | 1 : 125,000 | 100 | 6,600 |
| Wyoming | ........ | 2 | 1 : 125,000 | 100 | 600 |
| Yellowstone National Park | 2 | 2 | 1 : 125,000 | 100 | 3,000 |
| Total | ........ | ........ | ............ | ............ | 285,000 |

As these tables indicate, the maps are drawn on different scales in different regions, being approximately one mile to the inch in Massachusetts, Wisconsin, and Ohio; two miles to the inch in the southern Appalachians, in Missouri, Kansas, Texas, and California, and four miles to the inch in New Mexico, Oregon, and Montana.

In the earlier work of the Geological Survey it was contemplated that a large part of the general topographic map should be projected upon a scale of four miles to the inch. This was believed to be the smallest scale which could be used with advantage and to be the least costly. The last two years, however, have brought great improvements in the methods of work in the instruments and appliances, and, above all, in the skill and efficiency gained by the topographers through experience and zealous emulation. The cost of the work per unit of area upon any given scale has greatly diminished, the qual-

ity and accuracy of the work have been much improved, and the rapidity with which a given grade of work may be accomplished has increased. At the same time the demand for maps of greater detail and upon a larger scale than four miles to the inch has been rapidly growing, not merely for scientific purposes, but far more for economic purposes.

The general utility of a map two miles to the inch is for all purposes many times greater than that of a map four miles to the inch, and a further increase of utility follows from increasing the scale to one mile to the inch. In those regions which are more thickly settled or capable of supporting a denser population, and in those which are undergoing a rapid development of their material resources, it has become manifest that the scale of four miles to the inch is too small for the utilitarian demands which are made of a map. Such regions are diversified by relatively smaller topographic features and smaller differences of altitude than the mountain regions, which can not sustain large and dense populations. It has, therefore, become practically imperative to enlarge the scale in some regions, while the original four-mile scale is still adhered to in the regions of high mountains and arid plains and plateaus. The increased cost which (other things equal) necessarily attends the production of larger scale and more accurate and elaborate maps, has in a great measure been offset by more economic and more efficient service resulting from constantly growing experience and skill in field and office work.

## PROGRESS IN GEOLOGIC WORK.

### ATLANTIC COAST DIVISION.

The examination of the swamp and marsh lands which has been described in preceding annual reports has been continued during the past year under the charge of Prof. N. S. Shaler. The large area of such lands along the Atlantic coast south of New York and their situation upon the coast line make them especially important, and even a subject of solicitude, in relation to the future development of the country.

Deleterious to health in their natural condition, an obstacle in the way of approach to the sea, repellant to the settler, to agriculture, and to manufactures, they yet hold out the hope of highly productive utilization through the judicious application of capital. Wherever they are susceptible of effective drainage they are generally among the most valuable lands for agricultural purposes, and their unhealthful condition can be ameliorated or even wholly remedied. There are over 100,000 square miles of such lands in the United States, a large proportion of which by good engineering can be rendered highly productive. Much of it abounds in peat and iron ores, and in South Carolina and Georgia it contains deposits of phosphates which are collected and treated in chemical works in steadily increasing quantities. The swamps and overflowed lands of the interior present analogous conditions. Professor Shaler has visited the everglade region of southern Florida along the coast to ascertain the facts with reference to the possibility of drainage, and has met with highly encouraging results. He has investigated such evidences as were accessible bearing upon the origin of the topographic features of the southern part of the peninsula, and especially those which are indicative of elevation or subsidence of the land in recent geologic time. He has also made a preliminary study of the phosphate deposits of South Carolina, and the results have been put in form to be published as a bulletin of the Survey.

Progress has been made in mapping the swamp districts of Massachusetts, and Professor Shaler has completed the mapping of those occurring in the vicinity of Abington and Newburyport. A large amount of special geologic work bearing upon particular questions now under investigation has also been done by Professor Shaler, and the details are set forth in his report.

### DIVISION OF ARCHEAN GEOLOGY.

In many parts of the United States extensive exposures of very ancient strata occur, embracing in some cases formations which are older than the oldest fossiliferous rocks of assignable age, in other cases formations of the same ages as some of the fossiliferous beds, but in a condition which indicates that they

have undergone great changes since their deposition. Not only have their component beds been tilted, bent, folded, dislocated, and distorted to extreme degrees, but their mineralogic contents and their textures have been more or less altered. One effect of this metamorphism has been the obliteration of any fossils they may originally have contained, and upon these the geologist mainly relies in determining the ages and relations of strata. The confusion into which these masses have been thrown by the forces which have fractured and distorted them has further increased the difficulty. The present state of knowledge concerning the origin, relative ages, and former condition of these strata, the nature of the processes which have wrought these profound changes in their constitution, and their relations with one another is very unsatisfactory, although no rocks have been more earnestly studied. While the knowledge which has been gained is vast in amount and highly useful in its way, it has not been of such a character that it could be grouped and generalized into broad inductions, and it has thrown comparatively little light upon the most important questions.

There are large areas within the United States where these rocks are exposed. The most extensive are the New England States, the southern Appalachians, the vicinity of Lake Superior, and many parts of the great mountain region of the West, and especially the ranges upon and near the Pacific coast. It is deemed of importance to the interests of geologic science in general, both of systematic and economic geology, to take up this subject and prosecute investigations of the older crystalline rocks with vigor. The two fields which are regarded as offering the best opportunities and prospects for these investigations are the New England States and the Lake Superior region.. In the former field Prof. R. Pumpelly has been diligently at work with several assistants. Convinced that the Green Mountains of Vermont and Massachusetts are more likely to yield desired results and to clear up the broader questions relating to the geology of New England, he has divided the country into zones across those mountains, and is prosecuting the investigation of their structure in great detail.

He has already ascertained the components of the Green Mountain series of strata, has gained considerable knowledge of their lithology and relations, and has made much progress towards unraveling their complicated structure and learning the processes by which their metamorphism was effected.

### LAKE SUPERIOR DIVISION.

The investigation of corresponding horizons in the Lake Superior region has been conducted by Prof. Roland D. Irving, and his assistant, Prof. C. R. Van Hise. They have made much progress towards a final separation of these older rocks and their proper classification. Through their careful researches in the field they have brought to light strong evidence that below the oldest fossiliferous rocks thus far systematized (the Cambrian system), and above the most ancient crystalline rocks of so-called Archean age (the Laurentian), there exists in the Lake Superior region a vast mass of matter resolvable into several subdivisions. This great group they find to consist chiefly of fragmental material of the same general nature and origin as the sedimentary sandstones, conglomerates, and shales of the later group, but usually much altered by metamorphic action. These fragments have not hitherto yielded any fossils whose forms are distinctly preserved or which can be specifically determined, but they present much other evidence that organic life was abundant during their deposition. The laboratory work has led to results equally significant. In studying the composition and textures of these rocks several new facts have been brought out which go far towards explaining the nature of the processes which have altered the strata, and which constitute some of the most important additions that have been made in recent years to our knowledge of the metamorphism of rocks. It is in these strata that the valuable ore beds and copper of the Lake Superior region occur, and the geological investigation is now so far advanced, that the material is ready for a large portion of the final mapping of these highly complicated and disturbed strata whenever the topographic sheets are finished. The untimely death of Professor Irving, on May 27, 1888, which was cer-

tainly hastened by his excessive zeal and devotion to the work in his charge, if not entirely due to it, has deprived the Geological Survey of one of its ablest and most energetic geologists and American science of one of its brightest ornaments. The charge of his division falls upon Professor Van Hise, who has fully proved his fitness to carry forward the work in this difficult field.

## GLACIAL DIVISION.

Study of the vestiges of glaciation has been conducted by Prof. T. C. Chamberlin. The New England States, New York, a large portion of Pennsylvania, and in general the States north of the Ohio River and east and north of the Missouri, constitute a region whose superficial deposits and soils, whose lakes and minor topographic features, have been profoundly modified and in great part made what they now are by the action of glaciers. This region, as well as the basins of the Great Lakes and the Canadian provinces indefinitely northward, was doubtless during a recent geologic period sheeted over with ice in a manner which finds a counterpart in the present condition of Greenland. This conclusion—and a similar one has been reached with respect to certain portions of Europe—rests upon a vast mass of circumstantial evidence so clear and convincing when fully understood, that it may be regarded as one of the most wonderful and pleasing examples of inductive reasoning, and one of the best established that the whole range of modern science affords.

Professor Chamberlin's work has been the investigation of the extent of this former field of ice and its boundaries, the nature of its action in shaping surface features, the chief incidents of its history, and the geologic and climatic changes which were associated with it as causes or effects.

Near the close of the Glacial Period there existed in the region now embraced in the valley of the Red River of the North and that of the Saskatchewan a great lake, to which the name "Lake Agassiz" has been given. Its former existence was first clearly shown and its approximate limits roughly defined by the late General G. K. Warren, of the Engineers.

A considerable arm or bay of this lake extended up the Red River Valley into Dakota and Minnesota. Its ancient beaches are still easily discernible. Its bottom received the deposits of sediment ground from the rocks by the great continental glacier upon whose western margin the lake was situated, and these deposits constitute those soils of the Red River Valley which have become so famous for their fertility.

In cooperation with the Canadian Geological Survey, in whose territory the greater part of Lake Agassiz was situated, Professor Chamberlin's assistant, Mr. Warren Upham, has made a study of the portions of this lake basin and of its beaches which lie within the United States. This work has already occupied Mr. Upham several seasons, is still in progress, and has brought to light many instructive and important facts. Examinations have also been made of glacial deposits in the Coteau du Plateau du Missouri of Dakota by Prof. J. E. Todd; in northern Illinois and adjacent parts of Indiana and Michigan by Mr. Frank Leverett; in Wisconsin by Mr. I. M. Buell; in Indiana by Prof. L. C. Wooster; and in Maine by Prof. George H. Stone. Large and important additions have thus been made to our knowledge of the distribution and action of the ancient ice-sheet and of the history of the continent during the Glacial Period.

## APPALACHIAN DIVISION.

The work of this division is in charge of Mr. G. K. Gilbert. It chiefly consists of the investigation of the general geology of that portion of the Appalachian region in which the mountains and ridges are composed of flxed and faulted rocks of Paleozoic age. For the purpose of ascertaining in detail and with precision the character and sequence of these rocks in different parts of the region, and the general character of the displacements by which their order is disturbed, the geologists of the division have surveyed with thoroughness certain selected belts of country crossing the great belt from side to side.

The preliminary work is now completed, and the assistants have this year begun the areal work proper, marking on the topographic map the areas covered by the several formations.

The unit for areal work is the atlas sheet, one-half degree square; each party is initially assigned a unit area, and when its survey has been completed is assigned another. The atlas sheet will also be the unit of publication.

The soils of the region are derived from the rocks. In part they are constituted by disintegrated rock not otherwise disturbed and holding its original position, but in part also they result from the transportation and sorting of disintegrated rock by streams, waves, glaciers, or winds. The complete mapping of the geologic features thus shows the distribution of the soils, and it has been determined to separate the data concerning soils and prepare a soil map to accompany each geological map. The field parties gather data for both at the same time.

An essay on the comparative stratigraphy of bituminous coal districts, in preparation by Prof. I. C. White and mentioned in previous reports, is nearly ready, and will shortly go to press.

## PACIFIC COAST DIVISION.

The economic work of the survey is carried on in two divisions—that of the Pacific Slope under Mr. G. F. Becker, and that of the Rocky Mountains under Mr. S. F. Emmons.

The ultimate object of this is to arrive at a more complete understanding than we now possess of the methods of deposition of the ores of metals and of the laws which govern them. Incidental to the attainment of this object much information is collected with regard to all the economic resources of the regions examined, and their development in those regions is materially facilitated and advanced.

No attempt has yet been made to complete a systematic study and survey of all the deposits of the Great West, but the course pursued has been to select for research a typical mining district, or a series of such districts, illustrating a particular type of deposits or the mode of deposition of a particular metal or metallic combination. Of these an exhaustive study is made, illustrated by maps and diagrams, and after thorough chemical and petrographical study of the material gathered the results are published in the form of a monograph.

CALIFORNIA DIVISION.

In this division, towards the close of the last fiscal year, Mr. Becker had completed a study of the quicksilver deposits of the western United States, the occurrence of these ores being so limited in extent that his monograph embraces all known deposits of this metal in the country, and a supplemental study of some European deposits has enabled him to gather complete data with regard to all known deposits of the world. During the current year he has been detained at Washington attending to the printing of this monograph, which is now nearly completed. In the mean time his assistants in California have been occupied in preliminary field studies of the Gold Belt of California, which will form the subject of his next monograph.

In the Rocky Mountain region the ores of the metals consist of such a variety of mineral combinations that they do not so readily admit of a segregation into classes based on their metallic contents alone. For the final generalizations they must, to a certain extent, be treated as a whole, but at the present rate of progress it will be many years before all the many mining districts of the region can be examined, owing to the unusual expenditure of time and money required as compared with other geological investigations involved. In researches for gold and silver ores the object is not the direct determination of the metallic wealth of a region, as yet comparatively unexplored or undeveloped, but the determination of certain general laws governing the occurrence of these ores in the most completely explored regions, which the miner or prospector himself may apply to the development of the less known areas. Owing to the delays necessarily attendant upon the publication of the monographs, the practice has been adopted of publishing the more important facts in advance of the final publication in the form of short articles in scientific periodicals or of abstracts in the annual reports. Thus, although Mr. Emmons's monograph on the Geology of Leadville, Colo., was issued from the press only during the current year, an abstract of it was published in 1882 in the Second Annual Report, and according to the testimony of those engaged in mining there it has been a very great aid in the economic development of the district.

The geological survey of the Gold Belt of California, under Dr. G. F. Becker, has made steady progress during the last year, and a map showing the larger geologic divisions will be ready for publication almost as soon as the topography of the area is completed. The transition from placer and hydraulic mining to lode mining, which has taken place in California, with a steady increase in the output by the latter method, renders this survey an important one, and Dr. Becker and his assistants have already discovered many facts which must ultimately be of great utility to that industry.

In connection with this division a large amount of laboratory work has been accomplished, and many facts bearing on processes of ore deposition and of the alteration of rocks have been established.

### COLORADO DIVISION.

During the current year field work has been done in the area already mapped in Gunnison County, Colo., which combines great metallic wealth with valuable deposits both of anthracite and bituminous coals. Further than this, Mr. Emmons has made preliminary examinations of other mining districts which may in the future be the field of detailed work. The preparation of the two monographs on the Ten Mile and Silver Cliff Mining districts, and on the Denver Basin, has been continued during the year, and abstracts and short papers have been published embodying some of the more important generalizations derived therefrom.

### YELLOWSTONE PARK DIVISION.

Under the charge of Dr. Arnold Hague the survey of the National Park has made much progress. A topographic map of Mammoth Hot Springs Basin has been made by Mr. Anton Karl, of the topographic corps, and maps of the other geyser basins have been completed. Dr. Hague's geologic work has been prosecuted in the eastern portion of the Park in the comparatively little-known area around the northern part of the Wind River Range and the Absaroka Range, which constitute some of the grandest features of the region. His inquiries have thrown much light on the geologic history of the features

of the Park and of the volcanic processes which produced such wonderful results. Many instructive studies have been made of the action of the geysers and hot springs, and of the mineral deposits to which they have given rise.

Dr. Hague's attention has been forcibly drawn to the importance of this reservation as a storage area for the head-waters of some of the largest upper tributaries of the Missouri and also of the Snake River. Yellowstone Lake is the largest natural reservoir of the Rocky Mountain region, and may be an important factor in the prosperity of future populations of the country adjoining the lower courses of the Yellowstone who will be dependent upon its waters for irrigation.

Dr. Hague has devoted much time to the investigation of this important subject, and has obtained information which can not fail to be of great value in the future deliberations of Congress upon questions relating to its policy towards the public lands upon this broad water-shed of the continent.

### CORRELATION OF FORMATIONS.

In order to develop the geological history of the United States as a consistent whole, it is necessary to correlate the various local elements. The events of one district—the succession of eruptions, sedimentary deposits, and erosions—must be connected with the synchronous events of other regions. It is especially important to determine the synchrony of deposits. So far as the outcrops of strata can be continuously traced, or can be observed at short intervals, correlation can be effected by the study of stratigraphy alone. The correlation of strata separated by wide intervals of discontinuity can be effected only through the study of their contained fossils. This is not always easy, and it is now generally recognized that it is possible only within restricted limits. As distance increases the refinement in detail of correlation diminishes.

Recent discussions in connection with the work of the International Congress of Geologists have shown that different students assign different limits to the possibilities of correlation, and give different weights to the various kinds of paleontologic evidence employed.

The study of the data and principles of correlation is thus seen to be a necessary part of the work of the Geological Survey, and by making the study at the present time it can offer a timely contribution to general geologic philosophy. It has therefore been determined to undertake the preparation of a series of essays summarizing existing knowledge bearing on the correlation of American strata. It is proposed to have a treatise prepared by a competent specialist on each of the following systems: The Quaternary, the Newer Tertiary, the Older Tertiary, the Cretaceous, the Jura-Trias, the Carboniferous, the Devonian, the Silurian. the Cambrian, the Eparchean, and the Archean.

Each essay will consider the several geographic provinces of the system it treats, the stratigraphic divisions that have been made in the several provinces, the extent to which these divisions can be correlated with one another, the degree of precision with which the upper and lower limits of the system can be correlated with the limits of the corresponding European system, and the extent to which the American subdivisions can be correlated with the European. It is proposed to treat separately the evidence from vertebrate fossils and the evidence from fossil plants as to all the systems in which they are found; and there will be prepared in connection with the work a thesaurus of North American stratigraphic terminology.

The work has been placed under the general charge of Mr. G. K. Gilbert, and a number of specialists to assist him have already been selected from the various divisions to the Survey.

### DIVISION OF VOLCANIC GEOLOGY.

Large areas in the western portion of the United States disclose eruptive rocks and strata consisting of fragmental matter erupted from volcanic vents. In past periods of geologic time the activity of the volcanic forces in the western part of the continent was upon a scale of magnitude which may have surpassed anything of the kind which has been witnessed in historic times in any part of the world. In the northwestern parts—in Washington Territory, in Idaho, and in Oregon—also in the northern parts of California and Nevada,

it may be said that the surface rocks are chiefly volcanic. The great mountains of the Cascade Range—Baker, Ranier, St. Helens, Adams, Hood, Jefferson, Pitt, Shasta, and Lassen—are all extinct volcanoes. The spaces between these mountains are covered by accumulations of lava which issued from hundreds of vents, and some of which are thousands of feet in thickness. Although volcanic action seems to have produced its greatest effect in those regions, there are other portions of the West where the scale of activity was not generally inferior. In the history of the evolution of the continent, especially in its latter periods, volcanic action has played one of the most important parts.

The investigation of the volcanic fields has engaged Capt. C E. Dutton for several years, but owing to the general distribution of eruptive rocks over the western half of the continent, his labors have necessarily been limited to special areas.

During the last three years his principal field has been the Cascade Range in northern California and Oregon. The topographic work in this field has begun and made progress north of the fortieth parallel and west of the one hundred and twentieth meridian as far as the Pacific, and is rapidly extending in southern Oregon. Captain Dutton has made preliminary reconnaissances in the Cascade Range from the north end of the Sierra Nevada as far as the Columbia River, and has already grasped the broader and most obvious features of the structure, extent, and constitution of this great range, and its relations to the westward coast ranges bordering upon the Pacific. During the past season his assistant, Mr. J. S. Diller, has completed the mapping of the geologic formation upon two of the completed atlas sheets in the vicinity of Lassen Peak and the northern part of the Sacramento Valley. The results of this investigation have already thrown great light upon the history and structure of the region thus mapped, and solved some of the most important questions relating to its structure and stratigraphy.

One of the essential processes in the study of the volcanic eruptions is a careful examination of the constitution of the lavas and their associated minerals. For this purpose the microscope is one of the most important instruments, enabling

the investigator to determine the minerals by their optical properties. The preparation of the rock specimens in the form of thin sections is one of the chief functions of the petrographic laboratory. The rock specimens which have been collected by all divisions of the Survey and which require microscopic examinations are sent here for cutting, grinding, and mounting in a suitable manner. Under the immediate charge of Mr. J. S. Diller this most useful adjunct of the Survey has performed a large amount of work in a highly satisfactory way.

For nearly two years Captain Dutton has been also occupied in the investigation of the Charleston earthquake and in preparing a monographic report upon it. In many respects the best observed earthquake which has ever occurred, and perhaps the most carefully studied, it has yielded results which undoubtedly add to our knowledge of such phenomena. But Captain Dutton, after two years of most laborious investigation, is still of the opinion that the result adds but little to our knowledge of the ultimate causes which produce such catastrophes. His work upon this earthquake constitutes the most extensive contribution to the scientific papers embodied in this volume.

### POTOMAC DIVISION.

Along the border of the Piedmont region of the Atlantic slope, extending from northern New Jersey as far south as Alabama, there occur certain formations which have attracted the inquiries of geologists ever since the year 1835. Their relations to adjoining strata and their ages were very imperfectly understood until two or three years ago. As these formations are an important factor in the stratigraphy of the Atlantic region, it seemed desirable that they should be thoroughly investigated. The subject was assigned to Mr. W J McGee, who began the examination in the District of Columbia, where these formations are well exposed. The result of his field work has been gratifying. Extending his researches both north and south along the margin of the Piedmont region, he has examined many exposures, and has discovered localities within it which have yielded fossil plants and vertebrates.

The vertebrate fossils have been examined by Prof. O. C. Marsh, who has been able to fix their age as Upper Jurassic. The plant remains have been examined by Prof. W. M. Fontaine, and are found to be in the main new types which combine the features that characterize the floras of the Lower Cretaceous and early Jurassic systems.

Thus the primary point regarding these formations may be considered to be established, and it remains only to trace them out upon the ground in their full extent. When this is accomplished, a considerable gap in our knowledge of the distribution of the geologic formations of the Atlantic slope will be in great part closed. The name of the Potomac formation has been given to this series of strata, in conformity with the usual practice of naming formations after the typical localities which first yield the data requisite for assigning them to their true positions.

East of the belt in which the Potomac formation is disclosed and adjoining it there are found other formations of later age, which have also been a subject of equal uncertainty. Mr. McGee has studied them with much care, and has succeeded in resolving them into subdivisions and in ascertaining some of their most important relations to one another and to the subjacent formations and in assigning to them approximately their respective ages. They are of late Cenozoic and recent deposition. They have important relations to the later stages of the development of the continental border, and throw light upon the origin and changes of its topography and drainage system. The investigation of these formations in their wider distribution during the past year has made progress and will be continued.

Much uncertainty has existed regarding the age and relations of certain Cenozoic strata in the State of Mississippi. Much had been done by the earlier work of Prof. E. W. Hilgard upon early Cenozoic formations of that State, but numerous important questions still require investigation. Mr. Lawrence C. Johnson has been engaged during the year in further field work upon these problems, especially with a view of ascertaining the relations of what is termed the Grand Gulf

series of beds. He has succeeded in finding them lying with apparent conformity upon the beds of Eocene age, which have been named the Vicksburg and Jackson beds by Professor Hilgard. He has also made progress in tracing the distribution of all these formations and distinguishing them from one another throughout the State, preparatory to the completion of the topographic work and the mapping.

### MONTANA DIVISION.

Since the death of Dr. F. V. Hayden the geological work of this division has devolved upon Dr. A. C. Peale.

The field is an important one, on account of the greater fullness with which the Paleozoic strata of the West are represented and the greater facility with which their correlations with strata of corresponding age in the East and in the Upper Mississippi Valley can be traced. In some sense they may be said to form a connecting link between the eastern and western Paleozoic systems. Strata of Mesozoic age are also well represented. Dr. Peale's field work has been chiefly in the valleys of the Gallatin and the Madison and Jefferson forks of the Missouri, and although the region is considerably disturbed and complicated by the flexing and faulting of the strata, he has accomplished much in the way of ascertaining their true relations and providing material for the geological mapping of a large section of the country.

In addition to this work Dr. Peale has been engaged in the office in the collocation of statistics relating to the mineral waters of the United States, which will be published in a volume of Mineral Resources.

### PROGRESS IN PALEONTOLOGIC WORK.

The amount of work accomplished in the collection and study of fossils during the year has been large. Although no new discoveries of exceptional importance have been made, the large amount of useful information collected in this field and the thoroughly effective manner in which it has been handled and systematized have made the total result highly gratifying.

## TENDENCY TO SPECIALIZE.

In no field of science is the tendency to subdivide itself into highly specialized branches more strongly marked than in paleontology. It arises from the vast and ever-increasing number of new species which are added yearly to those already known, until it transcends the capacity of the human mind to become familiar with more than a very limited group. To extend the group and control the investigator as much as possible, it is necessary to devise methods by which he may be able with the least possible expenditure of time and labor to avail himself of the discoveries, figures, and dimensions which have been recorded by previous investigators.

It is obviously impossible for the paleontologist to become familiar by personal examination of the fossils with the myriads of species within his chosen subdivision of the branch, far less could he study and retain the distinctive characters of each. The most he can do is to become acquainted with the leading types and their broader characters, and he must have recourse, as occasion arises, to the literature of the subject for further details. For this purpose various devices are necessary, such as bibliographies, card-catalogues, species-indexes. Thus a large portion of the work of the paleontologist must be devoted to the elaboration of a system which will enable him to obtain and keep command of his subject.

## METHODS OF COLLECTION AND CLASSIFICATION.

Another important portion of his work is the maintenance, enlargement, and thorough classification of the collections of fossils which have been gathered by many students during many years and brought together in the National Museum. These fossils are not, as might be supposed, for the wonder and entertainment of the curiosity-seeking visitor, but are chiefly for the use of the paleontologist, who resorts to them for purposes of comparison and for establishing the specific identity or nearest relationship of the fossils which from day to day reach his hands. To facilitate his command of the resources of these collections he is, whenever practicable, made an honorary curator of the Museum in the department of that

institution embracing his special field. For this work he receives no additional compensation. He is also called upon every year to perform more or less field work. Since the ages and relations of strata in the stratigraphic system are assigned chiefly upon the testimony of the fossils which they contain, and since many formations are undetermined in these respects through imperfect knowledge of their fossil contents, it frequently becomes necessary for the paleontologist to visit doubtful or little-known localities, to gather with his own hands the required evidence, and, after careful examination of typical localities, decide, if possible, the disputed or unsettled questions. And, finally, the fossils collected throughout the country by the geologists are referred to him for determination.

### VERTEBRATE PALEONTOLOGY.

In the past year, in the branch of vertebrate paleontology, Prof. O. C. Marsh has made further collections in the Miocene formations of Dakota and in the Jurassic deposits of Wyoming and southern Colorado. One of the most important of his discoveries has been the finding of a considerable number of vertebrate fossils in the outcrops of the Potomac formations between Baltimore and Washington. These fossils serve to settle the long-contested problem as to the age of this formation, and to place it in the Upper Jurassic. Professor Marsh has also made progress upon his monographs of several orders of the fossil vertebrates, which constitute a series of high importance to general geology and paleontology.

The subject of invertebrate paleontology has been subdivided into three divisions, embracing respectively fossils of Paleozoic, Mesozoic, and Cenozoic ages. In the Paleozoic division Mr. C. D. Walcott has devoted most of his field work to the investigation of the Cambrian and Lower Silurian strata of the Hudson River Valley and of Vermont and western Massachusetts. He has had great success in discovering fossils which have been the means of clearing up much of the doubt and uncertainty regarding the ages and relations of the strata in those localities. His work has also had special reference to the long-disputed questions as to the true position, extent, and

significance of the Taconic system of Dr. Emmons in the localities where that eminent geologist originally studied it and in the Green Mountains to the northward. Mr. Walcott has done much towards the final solution and settlement of those difficult problems.

### INVERTEBRATE PALEONTOLOGY.

Dr. C. A. White, whose principal field is the study of Mesozoic invertebrate paleontology, has carried forward his examinations of the Lower Cretaceous formations of Texas, whose age he succeeded in establishing last year, and he has made much progress in further correlating them with formations to the eastward in the Lower Mississippi Valley, and in ascertaining their extent and distribution. He has pushed his inquiries upon the southward extension of the Laramie group to the early marine Cenozoic formations in Texas with important results. He has also made examinations of the extent of the Cretaceous formations of Mississippi and Alabama, to obtain some much-desired data contributory to a work he is preparing on the subject of the Cretaceous strata in the United States. During the year he has prepared a considerable number of papers on the Mesozoic fossils of the country.

### CENOZOIC INVERTEBRATE FOSSILS.

Dr. W. H. Dall, whose work is chiefly in Cenozoic invertebrate paleontology, has directed and conducted a large amount of field work in northern California, in Florida, and in New Jersey—the work in Florida being especially noteworthy. Through the cooperation of Mr. Joseph Willcox, the examination in that State has shown the extension of the Miocene formations farther south and of the Pliocene farther north than had been formerly recognized. In the northern part of the everglades coral limestone has been discovered similar to that described by Agassiz in the Florida keys. As a large number of private individuals are engaged in various parts of the country in the study of the Cenozoic strata and fossils, Dr. Dall has given much time and attention to methods of cooperation with such work and to the encouragement of it, furnish-

ing such information and assistance as the Government collections afforded.

### FOSSIL PLANTS AND FISHES.

During the year Mr. Lester F. Ward has diligently prosecuted the study of fossil plants. He has made extensive collections in the coal-bearing strata in the vicinity of Bozeman, Mont., and in the celebrated fossil forests of the Yellowstone, in the vicinity of Amethyst Mountain, and within or near the National Park. In the office a considerable amount of work has also been accomplished preparatory to a general bibliography of fossil plants, and in completing a species-index, illustrated by a large number of drawings.

During the fiscal year Dr. J. S. Newberry has completed and forwarded to this office a monograph upon "The Fossil Fishes and Plants of the Triassic Rocks of New Jersey and the Connecticut Valley." It contains figures and descriptions of all the species of fishes and plants found up to the present time in the Triassic areas of the North Atlantic States, and constitutes a most valuable contribution to our knowledge of paleontology. He has also finished and submitted a monograph on "The Paleozoic Fishes of North America," a work of even greater importance, which he was requested by this office to undertake. In the month of September, 1887, he made special studies of the Laramie group in Colorado, tributary to a memoir he is preparing upon "The Cretaceous and Tertiary Floras of Western America," upon which great progress has been made. Another memoir which he is preparing for the Survey upon "The Flora of the Amboy Clays of New Jersey" is also in an advanced stage of progress. These works of this distinguished geologist and paleontologist will all possess a high value and form important additions to the science.

Prof. W. M. Fontaine has made numerous studies of fossil plants. He has obtained and examined extensive collections from the Tuscaloosa formations in Alabama, and the result of his inquiry appears to be that these beds are nearly, if not quite, of the same age as the upper members of the Potomac

formation, which is adverted to in the accounts of the researches of Professor Marsh and Mr. McGee. The fossil plants of the Potomac formation in Maryland and Virginia have been studied by Professor Fontaine and reported upon.

### FOSSIL INSECTS.

Prof. H. S. Scudder has been long engaged in the study of the fossil insects of North America, and has made special examination of a remarkable group of such fossils obtained from Florissant, in Colorado, and of a group obtained from the carboniferous coal fields of Rhode Island. The literature of this highly specialized branch of paleontology being scattered throughout a wide range of periodical publication, Dr. Scudder has undertaken the compilation of a reference index in a systematic form, which will make that literature readily available for future research. The preparation of a preliminary card-catalogue has occupied a considerable portion of his time.

## MISCELLANEOUS.

### MINING STATISTICS AND TECHNOLOGY.

It has been the custom of this Survey to prepare annually a report of the statistics showing the production during each year of the metals and mineral products of the country. This annual report is received with high favor by thousands of persons engaged in production and trade, to whom the information is of mercantile value. It contemplates the collocation of the output of all metals, minerals, stones, coal, petroleum, natural gas, and in general all inorganic substances taken directly from the earth for industrial and commercial purposes, together with an estimate of their money values.

Dr David T. Day, in charge of this division, estimates that for the calendar year 1887 the total value of such products was $542,331,796, being larger than for any preceding year in the United States, and the largest total for one year ever reached by the mineral production of any country.

This grand aggregate is due both to an increase in the quantity of material produced and to an increase in the aver-

age of prices. With every year's experience this division has gained facilities for procuring information concerning the amount and value of these products and of their relations to the various industries in which they are employed. It has won the confidence of producers and consumers alike, and finds ready cooperation on the part of many experts and well-informed persons throughout the country who are in positions where they can gather and return trustworthy information.

In the course of this work the corps of correspondents from whom returns of production were received was increased to about forty thousand. A tabulated statement of the results is given below. A separate investigation was also begun under Mr. Albert Williams, jr., which is intended to show geographically the position of all the known mineral deposits of commercial value, whether at present mined or not.

*Metallic products of the United States in* 1887.

| | Quantity. | Value. |
|---|---|---|
| Pig-iron, spot value ..........long tons.. | 6,417,148 | $121,925,800 |
| Silver, coining value ..........troy ounces.. | 41,269,240 | 53,441,300 |
| Gold, coining value ..........do.... | 1,596,500 | 33,100,000 |
| Copper, value at New York City..........pounds.. | 185,227,331 | 21,115,916 |
| Lead, value at New York City..........short tons.. | 160,700 | 14,463,000 |
| Zinc, value at New York City..........do.... | 50,340 | 4,782,300 |
| Quicksilver, value at San Francisco..........flasks.. | 33,825 | 1,429,000 |
| Nickel, value at Philadelphia..........pounds.. | 205,556 | 133,200 |
| Aluminum contained in alloys ..........do.... | 18,000 | 59,000 |
| Antimony, value at San Francisco..........short tons.. | 75 | 15,500 |
| Platinum, value (crude) at New York City..troy ounces.. | 448 | 1,838 |
| Total .......... | .......... | 250,466,854 |

*Non-metallic mineral products of the United States in* 1887 (*spot values*).

| | Quantity. | Value. |
|---|---|---|
| Bituminous coal ..........long tons.. | 78,470,857 | $98,004,656 |
| Pennsylvania anthracite..........do.... | 37,578,747 | 84,552,181 |
| Building stone.......... | .......... | 25,000,000 |
| Lime ..........barrels.. | 46,750,000 | 23,375,000 |
| Petroleum..........do.... | 28,249,597 | 18,856,606 |

*Non-metallic products of the United States, etc.*—Continued.

| | Quantity. | Value. |
|---|---|---|
| Natural gas | .......... | 15,838,500 |
| Cement ........ barrels.. | 6,692,744 | 5,186,877 |
| Salt ........ do.... | 8,003,962 | 4,093,846 |
| Limestone for iron flux ........ long tons.. | 5,377,000 | 3,226,200 |
| South Carolina phosphate rock ........ do.... | 480,558 | 1,836,818 |
| Zinc-white ........ short tons.. | 18,000 | 1,440,000 |
| Mineral waters ........ gallons sold.. | 8,259,609 | 1,261,473 |
| Borax ........ pounds.... | 11,000,000 | 550,000 |
| Gypsum ........ short tons.. | 95,000 | 425,000 |
| Manganese ore ........ long tons.. | 34,524 | 333,844 |
| Mineral paints ........ do.... | 20,000 | 310,000 |
| New Jersey marls ........ short tons.. | 600,000 | 300,000 |
| Pyrites ........ long tons.. | 52,500 | 210,000 |
| Flint ........ do.... | 32,000 | 185,000 |
| Mica ........ pounds.. | 70,500 | 142,250 |
| Corundum ........ short tons.. | 600 | 108,000 |
| Sulphur ........ do.... | 3,000 | 100,000 |
| Precious stones | .......... | 88,600 |
| Crude barytes ........ long tons.. | 15,000 | 75,000 |
| Gold quartz, souvenirs, jewelry, etc | .......... | 75,000 |
| Bromine ........ pounds.. | 199,087 | 61,717 |
| Feldspar ........ long tons.. | 10,200 | 56,100 |
| Chrome iron ore ........ do.... | 3,000 | 40,000 |
| Graphite ........ pounds.. | 416,000 | 34,000 |
| Fluorspar ........ short tons.. | 5,000 | 20,000 |
| Slate, ground as pigment ........ long tons.. | 2,000 | 20,000 |
| Cobalt oxide ........ pounds.. | 18,340 | 18,774 |
| Novaculite ........ do.... | 1,200,000 | 16,000 |
| Asphaltum ........ short tons.. | 4,000 | 16,000 |
| Asbestus ........ do.... | 150 | 4,500 |
| Rutile ........ pounds.. | 1,000 | 3,000 |
| Total | .......... | 285,864,942 |

*Résumé of the values of the metallic and non-metallic mineral substances produced in the United States in* 1887.

| | |
|---|---|
| Metals | $250,466,854 |
| Mineral substances named in the foregoing table | 285,864,942 |
| | 536,331,796 |
| Estimated value of mineral products unspecified | 6,000,000 |
| Grand total | 542,331,796 |

## CHEMISTRY AND PHYSICS.

This division, under the charge of Prof. F. W. Clarke, is engaged in the investigation of chemical and physical problems which are constantly arising in the course of geological field or office work. The chemical laboratory is now well equipped, and during the past year has accomplished four hundred and twenty-six assays and analyses of rocks, ores, and minerals. Very many requests for the identification of mineral substances coming from all parts of the country are referred to this division. From other bureaus of the Government requests for analyses are also received. Numerous original investigations have been made in the laboratory of problems in mineralogy and lithology, bearing more or less directly upon the geological investigations of other divisions and of questions in technical chemistry having special reference to economic geology.

Prominent among these is a research as yet unfinished on the origin and utilization of the vast stores of alkali salts contained in certain lakes in western and southern Nevada and eastern California. While questions of scientific value have received deserved attention in connection with this subject, the problem has been treated mainly from an economic standpoint, with a view to facilitate the development of the soda industry of that region. The investigation has excited favorable comment among those best qualified to judge of the commercial results that would follow a satisfactory solution of the problem mentioned.

Work upon the rocks and deposits of the Yellowstone National Park has been continued, likewise upon the occurrences of minerals containing the rarer elements, many of which are from year to year more sought for use in the industrial arts.

In the course of laboratory researches it is sometimes found that the methods of analysis in vogue are faulty or not adapted to the peculiar exigencies of the case in hand. In such cases it may become advisable to institute a collateral line of inquiry directed towards the improvement of existing

methods or the discovery of new ones. The value of work of this kind already accomplished is attested by the reception accorded by the scientific world to methods which originated in this laboratory in previous years and which are now being widely adopted.

Researches in the physical laboratory have resulted in a development of the methods of high temperature, air thermometry, and electrical pyrometry, and the addition of a new instrument of research, the transpiration pyrometer. Reliable methods for the measurement of high temperatures are among the most important desiderata of the day, and as their practical application has been constantly kept in mind, the work has economic importance apart from its geologic value. These investigations, together with that on solid viscosity, are preliminary to broader inquiries which involve pressure considerations.

The investigation of the co-efficient of thermal expansion of rocks recently undertaken is expected to furnish data very necessary to the satisfactory study and solution of some important questions in dynamic geology. At the same time, by the examination of various important building stones it is hoped that information will be obtained of considerable economic value to engineers and constructors.

## ILLUSTRATIONS DIVISION.

The work of the illustrations division covers the preparation of all illustrations for the Survey publications and all photography. A wide range of skill is required to conduct this work with success.

In the photographic laboratory, which is in charge of Mr. J. K. Hillers, the accurate reproduction of the maps and charts of the topographic corps, the photographing of geologic and paleontologic specimens, and the preparation of large transparencies of varied pictorial subjects call for skilled manipulation.

The preparation of illustrations for the various publications of the Survey, of which Mr. W. H. Holmes has charge, is a work of considerable magnitude. Certain branches of this

work require superior skill. The drawing of paleontologic specimens for the various specialists is perhaps the most exacting branch, and but few draughtsmen succeed in it. Mr. John L. Ridgway stands at the front in this class of work. Another branch worthy of especial mention is the preparation of illustrations of all classes for the engraver, the selection of methods of reproduction for these, and the criticism of proofs.

During the prolonged absence of Mr. Holmes in the field the work of this division was intrusted to Mr. De Lancey W. Gill, who acquitted himself with credit.

### DIVISION OF LIBRARY AND DOCUMENTS.

The work in this division has progressed in a satisfactory manner. More than six thousand titles have been added to the library, so that it now contains 51,563 books and pamphlets. Twelve thousand volumes have been in use outside of the library hall, as that number have been charged and returned during the year. Twenty thousand titles of the catalogue of the literature of North American geology have now been prepared, and of these 3,000 have been arranged with a view of issuing a catalogue of the literature of official geological exploration in North America as a section of the general work. Twenty thousand volumes of the publications of the Survey have been received from the Public Printer, and 48,815 volumes have been distributed. Of these, 3,277 were sold. The amount received from these sales and turned into the Treasury is $1,692.25.

## NECROLOGY.

### FERDINAND VANDIVEER HAYDEN.

Ferdinand Vandiveer Hayden was born at Westfield, Mass., September 7, 1829. He was the son of Asa Hayden and Melinda Hawley. Both his maternal and paternal grandfathers were soldiers in the Continental Army during the Revolution, and each lived to be nearly one hundred years old.

When Ferdinand was about ten years of age he lost his father, and two years later he went to live with an uncle who owned a farm at Rochester, Ohio. With him he remained six years, working on the farm and teaching school during his

sixteenth and seventeenth years. When he was about eighteen he refused his uncle's offer of adoption as a son, saying that he was going either to learn a trade, and become a master in it, or to study a profession. Without a cent in his pocket he walked to Oberlin, and stated his condition and desires to President Finney, of Oberlin College, who became interested in him and encouraged him to begin his college course.

He was the youngest member of his class, which he joined after one or two terms of classical study had been completed. He not only overtook it but maintained a fair standing in it, and he studied French besides. Like many of the students at Oberlin at that time, he had to meet his expenses solely by his own labors, farming and teaching. He was not given to sport, but when not at work was occupied with books. He was particularly fond of poetry, and was well read in general literature. He is remembered by his classmates as a very industrious young man, diffident in demeanor, but enthusiastic in whatever he undertook, imbued with the determination to make use of all the means in his power to make something of himself. His class historian at a reunion some twenty years after graduation wrote of him as follows:

"Ferdinand Hayden was the boy of the class. He was the youngest, and was peculiarly boyish in feelings and manners; susceptible, open to all impressions, frank, unconcealing; with all the trials of poverty and hard study, and a misunderstood nature, he yet pushed on, showing an amount of will and persistency that now looks remarkable in the distance. He was a good student, not always thoroughly prepared, yet knowing more always than he could tell. He was enthusiastic, easily carried away, and early showed the bent of his nature in the direction of the natural sciences. Ferdinand was little understood; to most of his teachers and classmates he was an enigma. They prophesied no success for him; they deemed him an enthusiastic dreamer, who would never conquer in practical life."

He graduated in 1850, the subject of his address being "The benefits of a refined taste." At that time the medical profession was the common road to geology and natural history, and

the fact that he soon began to study medicine is an indication of the drift of his mind. He graduated Doctor of Medicine at the Medical College at Albany, N. Y., in the early part of 1853. While thus engaged he first met the veteran geologist and paleontologist, Prof. James Hall.

The collections of Dr. John Evans in the Mauvais Terres of White River, made in 1849, had been described in the final report of Dr. D. D. Owen in 1852 and had attracted attention, and Dr. Hayden was employed by Professor Hall, in the spring of the year of his graduation, to visit the Bad Lands and make a collection of the Cretaceous and Tertiary fossils of that region, so that he did not undertake the regular practice of medicine.

His explorations of the West, thus begun, continued with little interruption for more than thirty years. This first expedition resulted in much interesting and important knowledge relating to the geological structure of the Missouri Region from Fort Pierre to Council Bluffs, and large collections were made. The mammalian fossils were studied by Prof. Joseph Leidy, and the new species of cretaceous invertebrates were described by Professor Hall and Prof. F. B. Meek, in a paper which contained also a brief vertical section of the beds from which the fossils were obtained, this being probably the first of Dr. Hayden's scientific writings, although it was not published under his name.

In the spring of 1854 Dr. Hayden returned to the Upper Missouri region, and spent two years in exploring it, mainly at his own expense. During these two years, mainly on foot, he followed the Missouri River from Fort Pierre to Fort Benton and the Yellowstone to the mouth of the Big Horn, and explored also considerable portions of the Bad Lands. The collections of fossils resulting from these explorations embraced a larger number of species than all those previously known from that locality, and many of them were of new and remarkable genera. These collections and researches mark an epoch in the geologic investigation of the Great West.

Dr. Hayden returned to St. Louis early in 1856, and in February received a proposition from Lieut. G. K. Warren, of

the U. S. Topographical Engineers, to make a report upon the Sioux Country, its topography, facilities for campaigning, etc. This proposition was accepted, so that the results of his labors during the three preceding years were utilized by the Government. In May he was appointed by Lieutenant Warren one of his assistants on an expedition to obtain information of the Missouri River. This expedition began its field-work on June 28, and the party returned to Washington in November.

In May, 1857, Lieutenant Warren was intrusted with the command of an expedition to the Black Hills of Nebraska, and he appointed Dr. Hayden geologist to the expedition. The party assembled at the rendezvous at the mouth of the Loup Fork in the latter part of June, and early in July the explorations were begun. This expedition returned to Fort Leavenworth December 4, whence Dr. Hayden proceeded to Washington.

During the summer of 1858, with Professor Meek, he made an exploring tour into what was then the Territory of Kansas. This was unusually successful, and the geological results were published in the Proceedings of the Academy of Natural Sciences at Philadelphia in January, 1859.

Dr. Hayden continued with Lieutenant Warren until 1859, and on April 22 was appointed naturalist and surgeon to the expedition for the exploration of the Yellowstone River. The expedition started in June, and reached the Yellowstone River, near the mouth of the Big Horn, about the middle of August. From this point it turned southward, and skirting the east side of the Big Horn Mountains went into winter quarters on Deep Creek, near the North Platte. In May, 1860, explorations were resumed, the expedition reaching Fort Benton about the middle of July, from which point the party proceeded via Fort Union, on the Missouri River, to Omaha, where the field party disbanded, October 4; and from this place Dr. Hayden proceeded to Washington. The breaking out of the civil war interfered with the publication of the geological results of the expedition, and it was not until 1869 that the "Geological Report of the Exploration of the Yellowstone and Missouri Rivers" issued from the Government Printing Office at Wash-

ington. While the expedition was in winter quarters during the winter of 1859–'60 Dr. Hayden occupied a part of the time in making notes upon the languages and customs of the Indian tribes with which he had come in contact. These notes were embodied in various publications.

In October, 1862, Dr. Hayden was appointed acting assistant surgeon of volunteers, and served until his resignation in June, 1865. Later in the same year he was brevetted lieutenant-colonel for meritorious services during the war. Dr. Hayden's services through that period were given largely to the superintendence of hospitals.

In the fall of 1865 he was elected professor of geology and mineralogy in the University of Pennsylvania, a position held until 1872, when the increased labors in the management of the Geological Survey of the Territories induced him to resign it. In the summer of 1866 he undertook another expedition to the Bad Lands of Dakota. The trip occupied fifty-two days, during which a circuit of 650 miles was made, and resulted in large and valuable collections of vertebrate fossils.

From 1867 to 1879 the history of Dr. Hayden is coincident with that of the organization which, beginning as the Geological Survey of Nebraska, became the Geological Survey of the Territories, and was finally known as the Geological and Geographical Survey of the Territories. In 1867 Congress set aside the unexpended balance of the appropriation for legislative expenses of the Territory of Nebraska, amounting to $5,000, for a geological survey of the new State. Dr. Hayden was designated to make this survey, and thus began the work to the success of which he devoted all his energies during twelve years. In April, 1869, he was appointed United States geologist, and thenceforward the work was conducted under the direction of the Secretary of the Interior.

One of the results of the expedition of 1871, and the one in which he took the greatest interest and pride, was the setting aside by Congress of the Yellowstone National Park. The idea of reserving this region as a park or pleasure ground for the people originated with Dr. Hayden, and the law setting it apart was written in great part by himself, and it was due to

his personal efforts that it was passed. From 1873 to 1876, inclusive, Colorado was the field of his operations, and his work had its consummation in the Atlas of Colorado, which largely increased our knowledge of the topographical and geological features of one of the most interesting portions of the West. In 1879 Dr. Hayden received an appointment as geologist from the U. S. Geological Survey.

For four years he was occupied in completing the publications of the Geological and Geographical Survey of the Territories. In 1883 he undertook field-work with the hope that his health might be benefited, and the three following field seasons he spent in Montana. He gradually became worse, and by the latter part of 1886 he was mostly confined to his bed. On December 31, 1886, he resigned his position as geologist, closing an honorable connection with the Government that included twenty-eight years of actual service as naturalist, surgeon, and geologist.

He died in Philadelphia December 22, 1887, leaving a widow but no children.

In 1876 the degree of LL.D. was conferred upon him by the University of Rochester, and in June, 1886, the same degree was awarded to him by the University of Pennsylvania.

He was a member of many of the American scientific societies, and he was also honorary and corresponding member of seventy foreign societies.

Dr. Hayden was one of the pioneers in the geological investigations of the West, and his labors extended over a vast territory which had hitherto been a terra incognita. He opened the region to detailed exploration, examining it topographically, geologically, and botanically with a view to the development of its natural history and its mining and agricultural resources. He popularized geology, and to the general interest excited by his enthusiastic labors is due in a large degree the existence and continuance of the present Geological Survey.

Although one of the main objects of the earlier expeditions with which Dr. Hayden was connected was the collection of fossils, still American geological science owes much to him, and he had reason to be gratified with the results of his scien-

tific labors. The first complete section of the Cretaceous and Tertiary formations of the West was made by Hayden and Meek, and the names the former applied to them have long been widely known.

Dr. Hayden was the first to demonstrate the fact that the Rocky Mountain region and the country adjacent were covered during the Tertiary period with lakes, the waters of which as the period progressed gradually changed from brackish to fresh, until late in the Tertiary there were numerous fresh-water lakes scattered all over the West from the Mississippi Valley to the Pacific coast.

He also demonstrated the fact that a large portion of the sediment found in those lakes was due to showers of volcanic ashes thrown into their waters and deposited in the stratified condition which they now present. He also drew the conclusion that the elevation of the Rocky Mountains began in Laramie time and continued throughout the Tertiary period, and suggested that even at the present time it is going on; and to this gradual and long-continued rise he attributed the formation of chasms and cañons.

As to Dr. Hayden's personal character, those who were closely associated with him knew best how sincere, unpretentious, and enthusiastic was his desire to forward the cause of science. The diffidence, approaching even to timidity, which impressed his fellow students at Oberlin characterized him throughout his life, and made it sometimes difficult to understand the reasons for his success. It was undoubtedly due to his energy and perseverance, qualities equally characteristic of him as a youth and in mature life. For energy in work he probably had no superior, and this, with his enthusiastic frankness, was the secret of his success. Although ever eager to defend what he believed to be right, he was always ready to modify his views upon the presentation of evidence. Intensely nervous and excitable and frequently impulsive in action, he was generous to a fault. His subordinates and coworkers all recognized that each one stood upon his own merits, and that each would be treated with friendly justice, and that due credit would be awarded successful effort. The same spirit actuated

him in respect to those not immediately connected with him. His views are expressed as follows in one of his earliest reports, when speaking of those who had preceded him: "Any man who regards the permanency or endurance of his own reputation will not ignore any of these frontiermen who made their early explorations under circumstances of great danger and hardship." His work for the Government and for science was a labor of love.

### ROLAND DUER IRVING.

The boyhood and youth of Roland Duer Irving were not marked by any event out of the ordinary course, yet to those who knew him from his earliest days it is of interest to look back to see how by degrees a nature always modest, simple, and deferential to the feelings and wishes of others became also firm and self-reliant.

He was born in the city of New York, on the 29th of April, 1847, and had but little passed his forty-first birthday when his promising career was cut short by death. His father was the Rev. Pierre P. Irving, a nephew of Washington Irving and a clergyman of the Episcopal Church. He was remarkable for simple, earnest piety, and himself possessed more than usual literary taste and ability. His mother was a daughter of the Hon. John Duer, afterwards chief justice of the supreme court of New York, and eminent as a lawyer, orator, and jurist. On both sides, therefore, Roland Irving may be said to have inherited a taste for literature and a faculty of expression, while from his grandfather seems to have come also the power of analysis, of reasoning, and of judgment, which is as important to the man of science as to the lawyer.

In 1849 his father removed to New Brighton, Staten Island, and there young Roland's youth was passed. Although to appearance robust and large for his age, he never had a strong constitution, but was subject to frequent and alarming attacks of illness, also to a weakness of sight, which proved his greatest obstacle through life. For these and other reasons his early education was at home, his sisters and his father being his instructors, and it was not until his twelfth year that he was sent to a classical school.

His teacher was in the habit of taking long rambles on holidays and Saturday afternoons with his favorite pupils, and on these occasions Roland was interested in collecting specimens of the rocks and minerals, especially the ores and asbestus, of which he found several deposits on the island. These he brought home and arranged according to their classes, giving to each its proper designation, and the time, place, and circumstances of its finding. He thus, even while a lad, became somewhat familiar with the geologic characteristics of Staten Island.

Although it seemed from this that he had a strong natural bent toward geological study, it was thought that he should have the advantage of a full collegiate course; and in the autumn of 1863 he entered the freshman class at Columbia College. But he was obliged to give up study altogether in his sophomore year, and he took a trip to England. He remained there six months, and on his return, in 1866, improved in health, he at once began to prepare for a course in the school of mines of Columbia College. The optical malady was still a serious obstacle, and to spare his sight, his text-book, for the greater part of his course, was read to him by his sisters and the diagrams described. This method of study was slow and tedious, but it probably served to strengthen a memory which was naturally retentive.

For two summers he found employment and practical experience at the coal mines of Wiconisco, Pennsylvania, and soon after his graduation he was made superintendent of smelting works at Greenville, N. J. While thus employed in the summer of 1870, President Chadbourne, of the University of Wisconsin, at the recommendation of Professors Newberry and Eggleston, entered into communication with him, which resulted in an invitation to the chair of geology and mineralogy in that university.

In 1872 he was married to Abby S. McCulloh, a daughter of John S. McCulloh, of Glencoe, Md., who survives him with three children, two boys and one girl.

Professor Irving published more than forty scientific treatises, long and short, aggregating several large volumes.

Professor Irving had had abundant preparation as a technical expert when he turned aside from mining engineering and entered upon original research. Of his work as a member of the University of Wisconsin President Chamberlin says:

"His thoroughness, his mastery of the subjects he taught, his facile grasp of difficult problems, his graphic and humorous exposition, his clearness of presentation, his perfect candor and sincerity, his earnestness, devotion, and indefatigable industry combined to make him an effective instructor and a worthy leader not only in the mere intellectual work of his professorship, but in those moral and manly influences which belong to the true teacher.

"Immediately upon coming to Wisconsin he began to search for problems within the reach of his individual and unaided efforts, and first fell upon the relationship of the Baraboo quartzites to the adjacent strata. Though but an amateur in original work, his native insight and sound habits of inspection and induction led him directly to the truth and to its demonstration. He proved beyond question that the formation of the quartzite greatly antedated that of the surrounding strata, and that what are now the quartzite hills stood as islands in the adjacent seas throughout the ages during which the adjacent formations were gathering as sediments about them. This was the firm foundation upon which his springing reputation was based. It commanded not only his own confidence, but that of other young scientists, who afterwards became his colleagues in official investigation, and who, upon a searching reexamination of this little work of his, found it good, and based on it their good opinion of him.

"Appointed in 1873 to a position upon the State geological survey, his first work called forth one of his marked personal characteristics. The metalliferous formation to which he was assigned had given rise to hopes of inexhaustible riches, and these had been fostered by flattering opinions given by incautious and inexpert, though probably sincere, explorers. With the single desire to ascertain the precise truth he applied exact methods, and soon ascertained that the metalliferous content presented a tantalizing approach to the percentage of richness

requisite to give market value, but fell so far short of it as to be but a lure to useless expenditure. To dash down high hopes, to disappoint invested interests, to interfere with speculative enterprises is, for a young man without an established reputation, a seemingly hazardous course. To tell the truth was to put his position and the survey in jeopardy. His report was entirely characteristic—perfectly clear, frank, and unhesitating. It was even unnecessarily blunt, and the storm which followed might easily have overthrown one less firmly grounded in the evidence of the correctness of his position. The ultimate outcome, in all essential features, justified his conclusions.

"The most important original work of Professor Irving relates to the geological structure of the Lake Superior Region. He was the first competent geologist to trace out in anything like its entirety the great copper-bearing series, which occupies a tract of 40,000 square miles, embracing, besides a large area in our own State, portions of Michigan, Minnesota, and Canada.

"A second great work was the tracing out more fully and the bringing into more close and consistent correlation the iron-bearing formations of Wisconsin, Michigan, and Minnesota, and their coordination with the Canadian formations on the north shore of Lake Huron, whence the term Huronian, applied to these formations, has been derived.

"Professor Irving was one of the first to discover that grains of sandstone, formed by the rounding of fragments of quartz, build themselves up again into crystals by the addition of material to their exteriors, and, what is especially significant, that this added material arranges itself in crystalline form in perfect molecular harmony with the nucleus about which it is gathered.

"Perhaps the most important single determination by Professor Irving, and one of the latest, was the demonstration of the origin of the iron ores of the Lake Superior region. By a series of admirable investigations he has traced step by step the transformation of the ores from the original earthy carbonates of iron to their present form. He has made it altogether

clear that originally they were deposited as sediments in a manner almost precisely identical with that of the iron ores of the coal fields of Pennsylvania. This has given great significance to the association of these ores with carbonaceous shales, and has led to the recognition, on the part of those who are alive to these important determinations, of the fact that as far back in the history of the world as the times which were formerly known as Azoic there existed carbon-depositing agencies competent to produce all the essential phenomena of the coal period. This prolongs in no insignificant way the vast backward reach of known geologic time.

"These solid contributions to knowledge will remain as Professor Irving's greatest monument. Believing that in their essentials they are firm truth, we rest in the conviction that they must ever form an essential part of knowledge, and that their influence will not cease until the knowledge of these things shall cease to be sought."

## JAMES STEVENSON.

In the death of its executive officer, Mr. James Stevenson, during this year, the Survey has suffered a great loss. He was a man to whom this Survey owed much, to whom the old surveys of the Territories owed more. Mr. Stevenson was born in Maysville, Ky., on the 24th of December, 1840. When but a boy of sixteen he became associated with Professor Hayden, and accompanied him upon the expeditions of Warren and of Raynolds into the region of the Upper Missouri and Yellowstone Rivers. His tastes led him rather to the observation of the customs and dialects of the Indians than to geology, and the facilities for such study granted him by the winters spent among the Blackfoot and Sioux Indians laid a sure foundation for that ethnologic bent to which he gave the greater part of his life, and confirmed him in it. An interruption came with civil war, during the whole of which Mr. Stevenson served, first as a private and afterwards as a subaltern of the Thirteenth New York Regiment. Resuming interrupted studies in 1866, he accompanied Professor Hayden to the Bad Lands of

Dakota, and from this expedition brought back that added enthusiasm which interested General John A. Logan in the subject of the exploration and development of our Territories, and inspired him with the idea of a survey which should do this as an arm of the General Government. In the Congress of 1866–'67 he proposed, in an amendment to the sundry civil bill, the appropriation of $5,000 for such a survey, under the direction of Professor Hayden, and, through the warm debate the matter aroused, pushed the amendment to its adoption.

From that beginning sprang the Hayden Survey, and during its existence Mr. Stevenson was its executive officer. That it lived to achieve such important results is due to his careful management. Its history from 1868 to 1878 is his history. With it he explored Nebraska, Colorado, and New Mexico; Montana, Idaho, Wyoming, and Utah. With it he made the first governmental survey of Yellowstone Park, which became a national reservation largely through his influence. He traced to their sources the Columbia and Snake Rivers. He climbed the Great Teton, and is the first white man known to have reached the ancient Indian altar on its summit. He discovered a new pass across the Rocky Mountains. Against his protest the largest island in the wonderful Yellowstone Lake bears his name, and the loftiest peak that overlooks it is called "Mount Stevenson."

In 1879 the Hayden Survey was ended, the Bureau of Ethnology of the Smithsonian Institution was organized, and the U. S. Geological Survey was established. Mr. Stevenson, by virtue of his eminent fitness, became the executive officer of the new Survey, and was detailed for research in connection with the Bureau of Ethnology. In the years since then he has devoted the winters—from the incoming of the field parties to their outgoing in the spring—with rare tact to the emergencies and business of the survey; his summers to his favorite researches. He explored the cliff and cave dwellings of Arizona and New Mexico; he unearthed in the Cañon de Chelly two perfect skeletons of its prehistoric inhabitants; he investigated the religious mythology of the Zuñis, and secured a

complete collection of fetich-gods, never before allowed out of their possession; he studied the history and religions of the Navajos and the Moquis, and made an invaluable collection of pottery, costumes, and ceremonial objects. In the high mesas in which his explorations lay in 1885 he was attacked by the "mountain fever" in its worst form. It was his first serious illness, and his regular and temperate life saved him for the time. But a visit to the same region during the last year brought on a second attack of this peculiar and distressing disease, from which he did not rally so easily. He came home thoroughly prostrated, with signs of serious heart failure. From December, 1887, to July, 1888, the struggle for life continued with the best assistance under different climates, but the fight was plainly a failing one. With Mrs. Stevenson, he was returning from Gloucester, Mass., to Washington, that he might rest amid familiar faces when the end came with little warning. He died at the Gilsey House, in New York City, on the 25th of July. He is buried in the cemetery of Rock Creek Church near Washington.

Mr. Stevenson left few manuscripts behind him; but of these some are of great interest. He was too busy to write much. He was emphatically a man of deeds, not of words. On the one hand this might seem to be a fact to be regretted; but, on the other hand, if he had spent more time in recording there would have been less to chronicle. Splendid records he has left behind him at the National Museum in the complete groups of specimens of geyser phenomena, in the exhaustive collections of pottery, costumes, and ceremonial objects of the Pueblo Indians. These have made his fame as an original investigator. It must be left to others to chronicle how great it is.

### THOMAS HAMPSON.

Thomas Hampson, Chief of the Editorial Division of the U. S. Geological Survey, died of typhoid fever, at his home at Lanier Heights, near Washington, April 23, 1888.

He was born in New York City September 29, 1849, but spent his boyhood and youth in the town of Newburgh, N. Y., where he learned the trade of a printer. He early showed

unusual studiousness and quickness, and his ability was recognized by a clergyman of the town, who gave him evening lessons and prepared him to enter Cornell University, which he did in 1869. Here he had the double task of keeping up with the course of studies and providing for his own maintenance. He at once took high rank in his class, and soon won not only the esteem but the admiration of the college authorities. At the end of his third year, however, the strain told even upon his unusual powers of endurance, and President White strongly urged him to rest from college work for a year, during which time he could earn the means to take him through the remainder of the course without the necessity for outside work. The kind interest which prompted this advice took practical form, and, through President White's influence, Mr. Hampson obtained a place as compositor in the Government Printing Office in Washington. At the end of a year he resumed his studies. He graduated in 1874 and returned to Washington, where he was re-employed in the same establishment. In 1875 he became editor of the publications of the Bureau of Education. While Mr. Hampson gave conscientious attention to every detail of the onerous duties of his position, his labors did not stop there. In 1882 he entered the law department of Georgetown University, where he took the prescribed course with his accustomed thoroughness, graduating as bachelor of laws in 1884.

In 1885 he left the Bureau of Education to accept a position in this Survey, where he discharged with signal ability a higher order of duties of the same general character. He was not only charged with the typographic accuracy and tasteful presentation of all the publications of the Survey and of the Bureau of Ethnology, but with the corrections and emendations of the submitted manuscript. In this work his thorough knowledge of grammar, his keen literary tastes, and accurate acquaintance with Latin and modern languages gave his criticisms great value. Contrary to the general rule, by which authors are supposed to adhere tenaciously to their own formulation, the cases were rare in which Mr. Hampson's suggested emendations were not adopted.

Mr. Hampson married in 1878, and his widow and two young sons, to whom he was singularly devoted, survive him.

He had been for several years a member of the Cosmos Club in this city, and also belonged to the Philosophical and Anthropological Societies of Washington. At the time of his death he was adding to his official work the duties of editor of the American Anthropologist.

DEPARTMENT OF THE INTERIOR UNITED STATES GEOLOGICAL SURVEY.

# ADMINISTRATIVE REPORTS

OF

# CHIEFS OF DIVISIONS

AND

# HEADS OF INDEPENDENT PARTIES,

ACCOMPANYING THE ANNUAL REPORT OF THE

# DIRECTOR OF THE U. S. GEOLOGICAL SURVEY

FOR THE

## FISCAL YEAR ENDING JUNE 30, 1888.

# ADMINISTRATIVE REPORTS.

## REPORT OF MR. HENRY GANNETT.

DIVISION OF GEOGRAPHY,
*Washington, July* 1, 1888.

SIR: I have the honor to submit the following report upon the operations of the Division of Geography during the fiscal year ending June 30, 1888.

Geographic work was prosecuted during the year in the following-named regions, in most cases being an extension of the work of previous years: Massachusetts, the survey of which was finished; New Jersey, where the work consisted of primary leveling, the establishment of bench-marks, and revision of earlier surveys; the Appalachian region and the Atlantic plain south of Mason and Dixon's line; Kansas, Missouri, Texas, New Mexico, California, Oregon, and Montana. In addition to these areas the atlas sheet comprising Baltimore and its suburbs was surveyed, work was commenced in Arkansas and Iowa, and surveys begun under the direction of Prof. T. C. Chamberlin, in Wisconsin, were continued. The total area surveyed during the year is 52,062 square miles, which is distributed as shown in the following table, and in the map which constitutes Plate I. [Pocket at the end of this volume.]

| Region. | Scale of field work. | Scale of publication. | Area surveyed. |
|---|---|---|---|
| | | | *Square miles.* |
| Massachusetts and adjacent States | 1:30,000 | 1:62,500 | 2,350 |
| Baltimore and vicinity | 1:40,000 | 1:62,500 | 178 |
| Appalachian region | 1:126,720 | 1:125,000 | 16,525 |
| Missouri | 1:63,360 | 1:125,000 | 7,900 |
| Kansas | 1:63,360 | 1:125,000 | 1,000 |
| Arkansas | 1:63,360 | 1:125,000 | 4,000 |
| Wisconsin | 1:31,180 | 1:62,500 | 136 |
| Iowa | 1:31,180 | 1:62,500 | 950 |
| Texas | 1:63,360 | 1:125,000 | 4,050 |
| New Mexico | 1:126,720 | 1:250,000 | 7,200 |
| California | 1:63,360 | 1:125,000 | 1,436 |
| Oregon | 1:126,720 | 1:250,000 | 3,327 |
| Montana | 1:126,720 | 1:250,000 | 3,010 |
| Total | | | 52,062 |

The survey of this area completes seventy-four sheets of the General Topographic Atlas.

### ORGANIZATION.

No material changes in organization, excepting such as were incidental to the inauguration of the new work mentioned above, have been made. The changes in personnel are mentioned in their appropriate places.

### NORTHEASTERN SECTION.

This section has remained in charge of Mr. Marcus Baker, geographer.

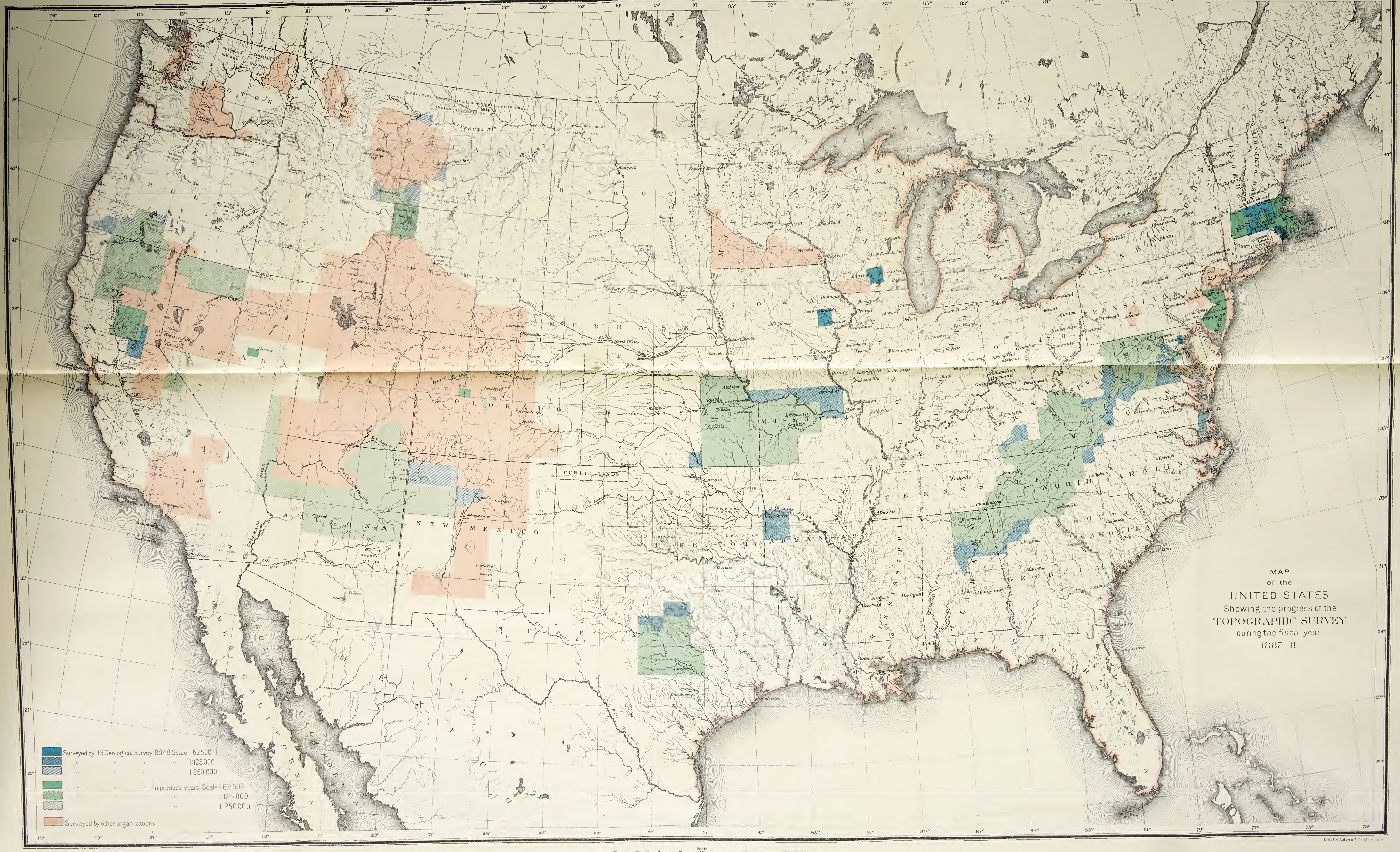
*Massachusetts subsection.*—The organization of work in Massachusetts was in most respects similar to that of the previous year. The work prosecuted by the intersection method with the plane table has remained under the immediate charge of Mr. Willard D. Johnson, topographer, and has been carried on mainly in the western part of the State. Mr. Natter, using the plane table, with a number of assistants engaged in traversing, has worked east of the central part of the State. Cape Cod and the islands of Nantucket, Martha's Vineyard, etc., have been surveyed by the traverse method.

At the beginning of the fiscal year field work was in active progress. Mr. Natter, with his assistants, Messrs. J. H. Jennings and William Kramer, was at work completing the Framingham sheet. In July Messrs. D. J. Howell, Clifford Arrick, and Robert Robertson, with rodmen, were added to his party. Besides completing the Framingham sheet, this party surveyed during the season the whole of the Groton and Fitchburg sheets, and completed the unfinished parts of the Palmer, Brookfield, and Providence sheets, an estimated area of 916 square miles. The field work of this party was completed and the men returned to Washington in the latter part of November.

Mr. Johnson's plane tablers were in the field and at work prior to the commencement of the fiscal year, Mr. R. D. Cummin being engaged upon the Marlborough sheet, Mr. W. H. Lovell upon the Greenfield sheet, Mr. Laurence Thompson upon the Belchertown sheet, and Mr. C. C. Bassett upon the Springfield sheet. Immediately after the 1st of July Mr. Johnson took the field to survey the Winchendon sheet personally. All of these sheets, together with the Warwick and the Barre sheets and the unfinished portion of the Webster sheet, were completed during the season, an area altogether of 1,362 square miles. The areas surveyed by the men individually are given below: Mr. Johnson, 211 square miles; Mr. Bassett, 241; Mr. Cummin, 323; Mr. Lovell, 339; Mr. Thompson, 248. It is to be noted that Mr. Johnson commenced work late in the season and that much of his time was taken up with supervision.

The survey of Cape Cod, Nantucket, Martha's Vineyard and the Elizabeth Islands was entrusted to Mr. E. B. Clark, who reported


Lith. by A.Hoen & Co. Baltimore


MAP
of the
UNITED STATES
Showing the progress of the
TOPOGRAPHIC SURVEY
during the fiscal year
1887 8.
Surveyed by U.S. Geological Survey 1887 8. Scale 1:62 500
" " " " 1:125 000
" " " " 1:250 000
" " " in previous years Scale 1:62 500
" " " " " 1:125 000
" " " " " 1:250 000
Surveyed by other organizations
WASHINGTON
OREGON
NEVADA
UTAH
COLORADO
KANSAS
MISSOURI
IOWA
NEBRASKA
DAKOTA
WYOMING
ARIZONA
NEW MEXICO
TEXAS
ARKANSAS
TENNESSEE
KENTUCKY
NORTH CAROLINA
SOUTH CAROLINA
GEORGIA
PENNSYLVANIA
MASSACHUSETTS
PUBLIC LANDS

directly to Mr. Baker. Mr. Clark commenced work early in the spring and completed the survey, reporting in Washington in the latter part of November.

During the winter the men were actively engaged in completing plane-table sheets, platting and adjusting traverses, and drawing their maps. It gives me pleasure to state that at this date the survey of the State, together with considerable areas of the adjoining States of New Hampshire, Vermont, New York, Connecticut, and Rhode Island, has been completed, the maps have been drawn and made ready for the engraver.

During the months of May and June, as the men engaged in the work of this subsection completed their office work, they resumed field work. In accordance with the agreement made with the commissioners of the State of Rhode Island, work was commenced in that State in the latter part of May. Mr. R. U. Goode, topographer, was temporarily detached from the western section for the purpose of extending triangulation over Rhode Island, from bases furnished by the U. S. Coast and Geodetic Survey. He has found great difficulty in executing this work owing to the fact that in late years the timber growth in the State has increased largely, requiring the building of high platforms for observing. He has pushed the work, however, with his usual energy and efficiency, and will complete it during the month of July.

For the purpose of establishing datum points for heights throughout the State, Mr. Frank Sutton was ordered there, with instructions to run lines with the Y level over the railroads and certain wagon roads. This work has been satisfactorily accomplished, Mr. Sutton having run in thirty working days 183 miles of level, establishing bench-marks at every road crossing, and giving a primary basis for the vertical element of the survey.

During the month of June Messrs. E. B. Clark, J. H. Jennings, and William Kramer were ordered to Rhode Island for the purpose of surveying the topographic details. In this work the plane table is being used as far as possible, making locations by intersection, while most of the details of the topography are obtained by stadia traverses. These parties report excellent progress.

About the middle of June Mr. W. H. Lovell resumed work in the portions of the Newburyport and Haverhill sheets which project from Massachusetts into New Hampshire, and Mr. C. C. Bassett commenced the survey of the parts of the Berlin and Pittsfield sheets which project from Massachusetts into New York.

Upon the completion of their office work Messrs. D. J. Howell and Laurence Thompson resigned from the Survey.

The survey of New Jersey leaves unfinished a number of sheets upon the northern and western borders projecting into New York and Pennsylvania. Mr. R. D. Cummin was detailed early in June

for the survey of certain of these sheets projecting into the Catskill plateau region of New York, where he is at work, while Mr. E. W. F. Natter, with Messrs. Jere. Ahern and W. R. Atkinson, who had been detached from the Appalachian section for the purpose, was assigned to the completion of such sheets as project into eastern Pennsylvania. Upon these he has recently commenced work.

*New Jersey subsection.*—Upon the nominal completion of the survey of New Jersey last spring, there remained an area of about 400 square miles, lying in the middle eastern part of the State, the maps of which had been compiled from existing county maps as far as horizontal location was concerned. The vertical element had been added to this by the State survey. It was deemed best to replace this horizontal element by our own surveys, and with this in view traverse work was carried on under Mr. Vermeule until its completion early in the autumn. In addition to this it was found desirable to establish certain bench-marks for levels. This also was completed, and the organization in New Jersey was broken up last November. At the end of May Mr. Vermeule himself severed his connection with the Survey.

*Baltimore subsection.*—During the past year an area having the dimensions of an atlas sheet and comprised between the meridians of 76° 15′ and 76° 30′ and the parallels of 39° 05′ and 39° 20′, including Baltimore and its suburbs, was surveyed, the work being in charge of Mr. S. H. Bodfish, topographer, who was assisted temporarily by Mr. J. H. Jennings, assistant topographer. The scale of field work was 1:40,000 and the contour interval 20 feet. The map is designed for publication upon a scale of 1:62,500. A part of this area was obtained from the Coast and Geodetic Survey, the portion surveyed by Mr. Bodfish comprising 178 square miles. The work was done with the plane table by intersections, but was supplemented largely by traverses of roads with the stadia.

The entire area surveyed by the northeastern section during the fiscal year is 2,528 square miles, no account being made of the revision work done in New Jersey.

### APPALACHIAN SECTION.

This section has, as heretofore, remained in charge of Mr. Gilbert Thompson, geographer. Its organization has comprised six topographic parties, and one party for furnishing control, while a number of topographers have been engaged upon independent work, disconnected from the regular parties.

Mr. Griswold was entrusted with the work of establishing primary control for the topography in the level country east of the Blue Ridge in Virginia. He attempted this by means of traverses of railway lines, connecting them at the ends to the triangulation of the Coast and Geodetic Survey. He obtained within the area be-

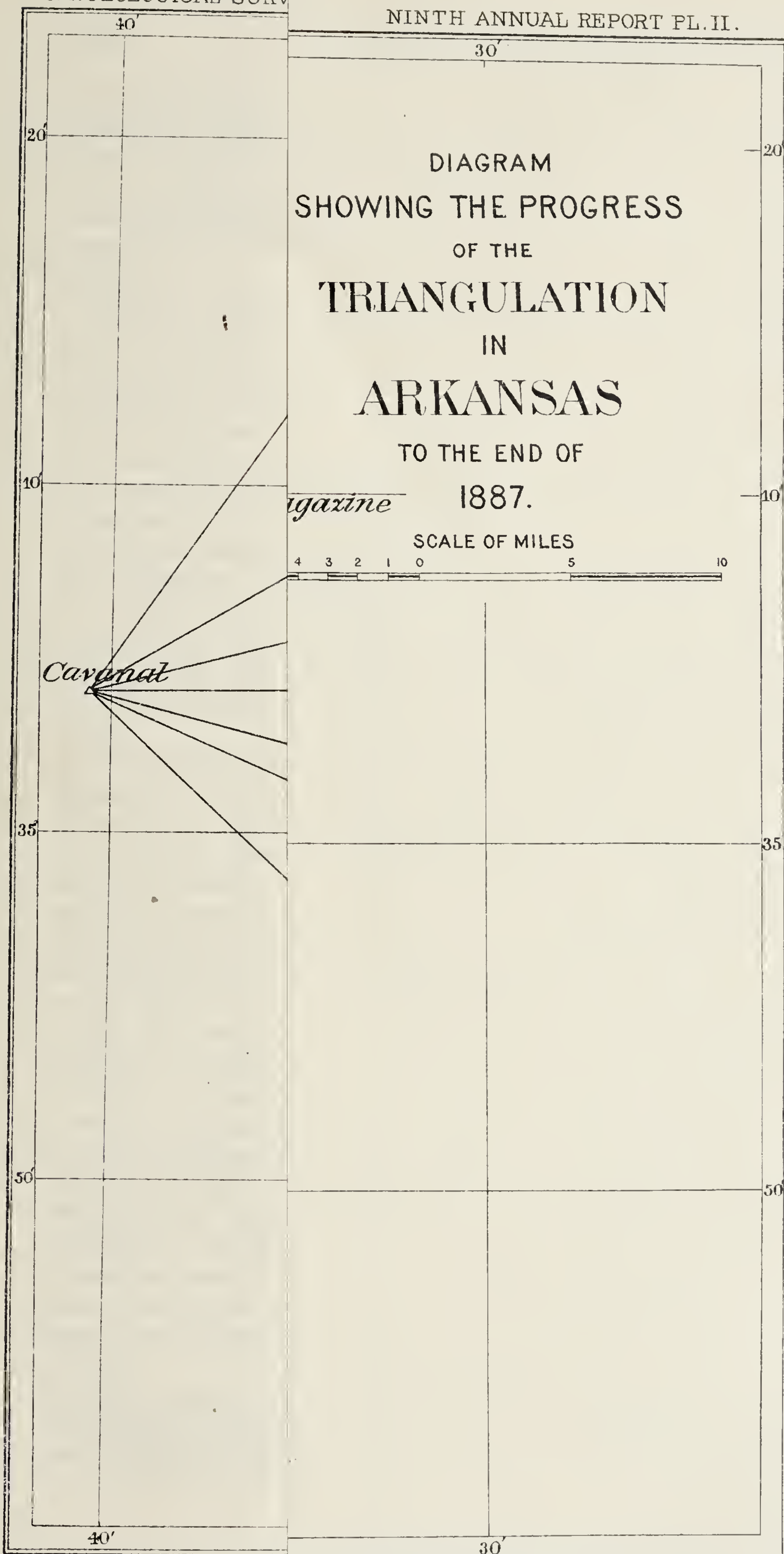



Photo-Lith. by A. HOEN & CO.

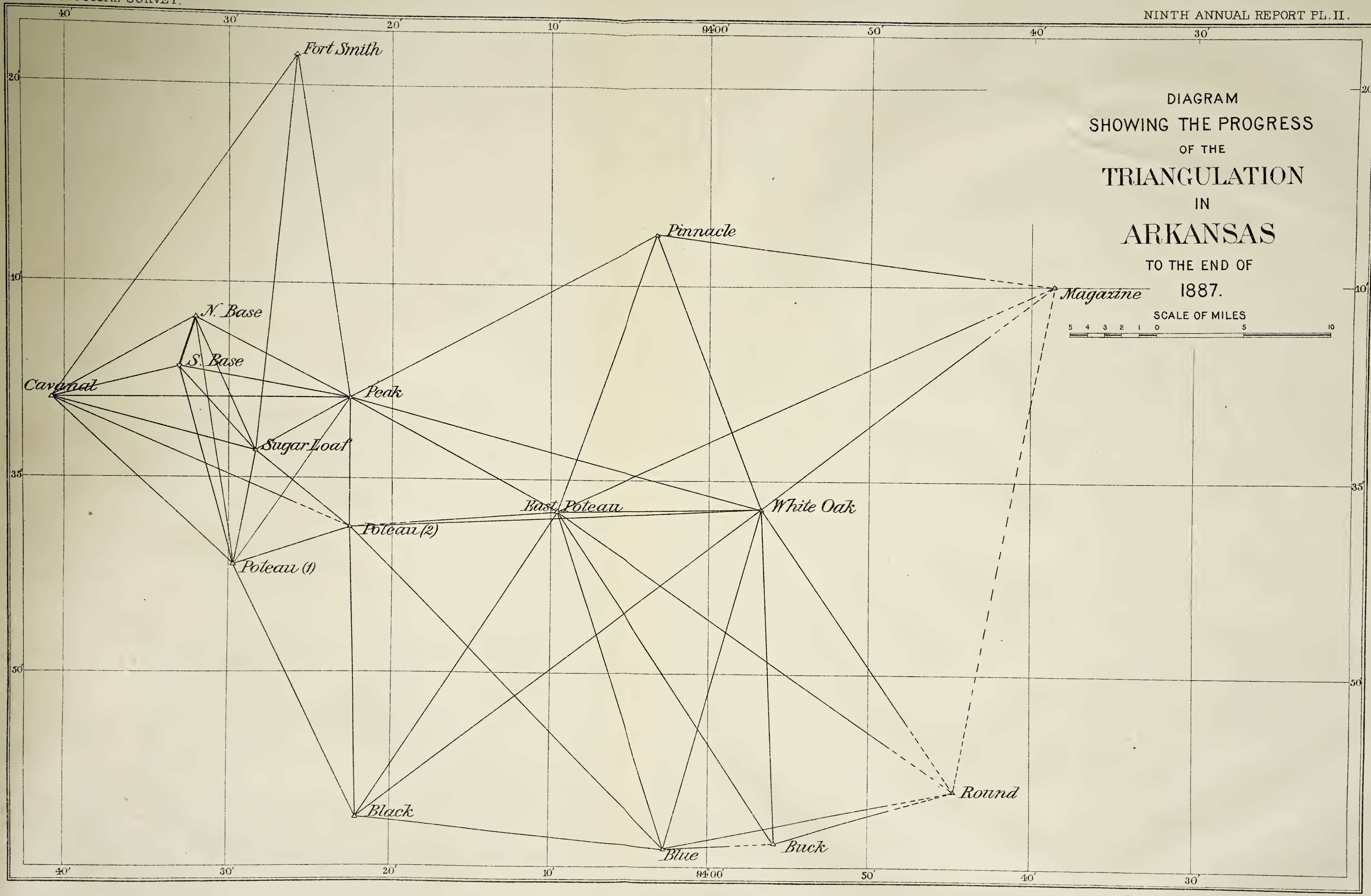



Photo-Lith. by A. HOEN & CO.

tween the Potomac and James Rivers lying east of the Blue Ridge the data for alignment from recent resurveys of nearly all the railroads. Such as were wanting he supplied, running the lines with a six-inch transit and a three-hundred-foot steel tape. This material when put together was found to meet the requirements, and the topographic work carried over part of the area above indicated rests upon it.

Mr. E. C. Barnard was placed in charge of a topographic party for the survey of that part of the Piedmont region lying south and west of the Potomac to latitude 38°, and extending westward to the line of previous work. Being a country of low relief, the contour interval was reduced from one hundred feet, the customary interval in the Appalachian region, to fifty feet, and the work was necessarily done entirely by traverse, using the compass and odometer. It was platted in the field by the traverse men. As assistants Mr. Barnard had Messrs. C. G. Van Hook, R. L. Lincoln, and R. L. Mitchell. Work was commenced on July 8 and closed about the middle of November. The party surveyed an area of 2,600 square miles, covering the region above indicated, with some overlapping areas, and completing four atlas sheets, with the exception of the parts lying upon the eastern shore of the Potomac in Maryland.

To Mr. Morris Bien was assigned the completion of the atlas sheets comprised in the degree between latitudes 37° and 38° and meridians 80° and 81°. As assistants he had Messrs. R. C. McKinney, C. E. Cooke, B. H. Monroe, Desha Breckenridge, Robert Breckenridge, and A. B. Searle. In addition to these, Mr. D. C. Harrison was detailed temporarily to this party. They commenced work July 8. On September 2 Mr. Harrison left the party, and on September 20 Mr. McKinney left it, to engage in independent work. The latter returned to this party on November 7 and remained until the close of the field work, on November 22. The party completed the area assigned it, mapping in all 2,500 square miles.

Mr. L. C. Fletcher was directed to complete the unsurveyed portions of the degrees between latitudes 38° and 39° and meridians 78° and 80°, lying partly in Virginia and partly in West Virginia. He left for the field July 1, outfitting at Staunton, Va., having as assistants Messrs. R. O. Gordon, W. J. O'Connell, C. H. De Butts, and H. W. Carpenter. Mr. Gordon left this party September 7 to prosecute independent work. Mr. Fletcher commenced work on July 6, and prosecuted it continuously until October 31, when he disbanded his party and returned to Washington, having mapped 2,500 square miles.

To Mr. Merrill Hackett was assigned the completion of the degree lying between latitudes 34° and 35° and longitude 84° and 85°, in northern Georgia, besides certain small outlying areas. He had as assist-

ants Messrs. A. E. Murlin, C. W. Goodlove, and S. H. Dent. The latter resigned on September 30, and Mr. James Graham took his place on the following day. Mr. Hackett commenced work on July 12, and between that date and the end of October surveyed an area of 2,100 square miles.

To Mr. Louis Nell was assigned an area in northern Alabama, comprising the completion of atlas sheets 33° 30′–85°, 33° 30′–85° 30′, together with as large a part as possible of the square degree lying between latitudes 33° and 34° and longitudes 86° and 87°. To him were assigned Messrs Jere. Ahern, W. R. Atkinson, W. L. Miller, F. P. Gulliver, and L. J. Battle. He commenced work early in July and worked continuously until the close of the season, disbanding on November 15. An area of 3,000 square miles was surveyed by this party.

To Mr. Charles M. Yeates was assigned an area in eastern Kentucky comprising the unsurveyed portion of atlas sheet 36° 30′–84°, together with atlas sheets 37°–83° and 37°–83° 30′. He was directed also to carry on such triangulation as was needed for the control of this area. As assistants there were detailed to his party Messrs. R. M. Towson, L. D. Brent, R. McC. Michler, A. E. Wilson, R. B. Cameron, and C. B. Buckstone. Work was commenced on July 12 and prosecuted until November 3, when the party was disbanded at London, Ky. Mr. Yeates, however, remained in the field with two assistants to attempt triangulation until December 10. During the season this party mapped about 2,000 square miles. The topographic work was moderately successful, but owing to the difficulties of the country and the prevalent bad weather, the triangulation is left in a weak condition, so that only a portion of this work can be completed at present.

To Mr. J. W. Hays was assigned the completion of the atlas sheets 36°–80° 30′ and 36°–81°, lying on the eastern slope of the Blue Ridge in North Carolina and Virginia. It was considered practicable to do this work without a party organization. He began work on July 5 and worked continuously until September 20, when, before completing the area, it was found necessary to assign him to other work. The area surveyed by him is estimated at 750 square miles.

On commencing work in the Appalachian region it was the intention that the maps should be published on a scale of 1:250,000, with contour intervals of 200 feet. After prosecuting the work for two years and before engraving any of the maps, it was found desirable to enlarge the scale to 1:125,000 and diminish the contour interval to 100 feet. The areas which had been previously surveyed were published upon this scale. Subsequent examination has shown the necessity for revising much of this early work in order to bring it up to the requirements of the scale. This revision was commenced during the past season and prosecuted as far as the means at hand

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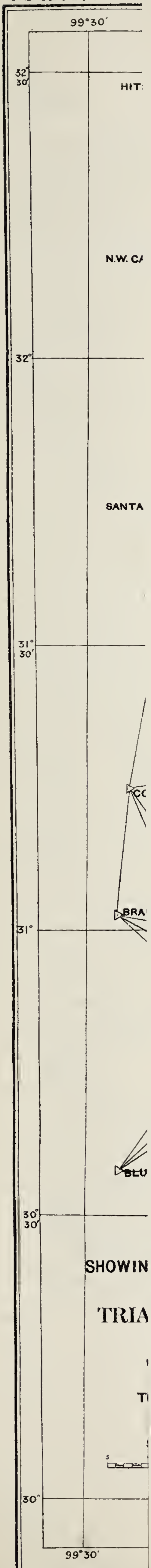


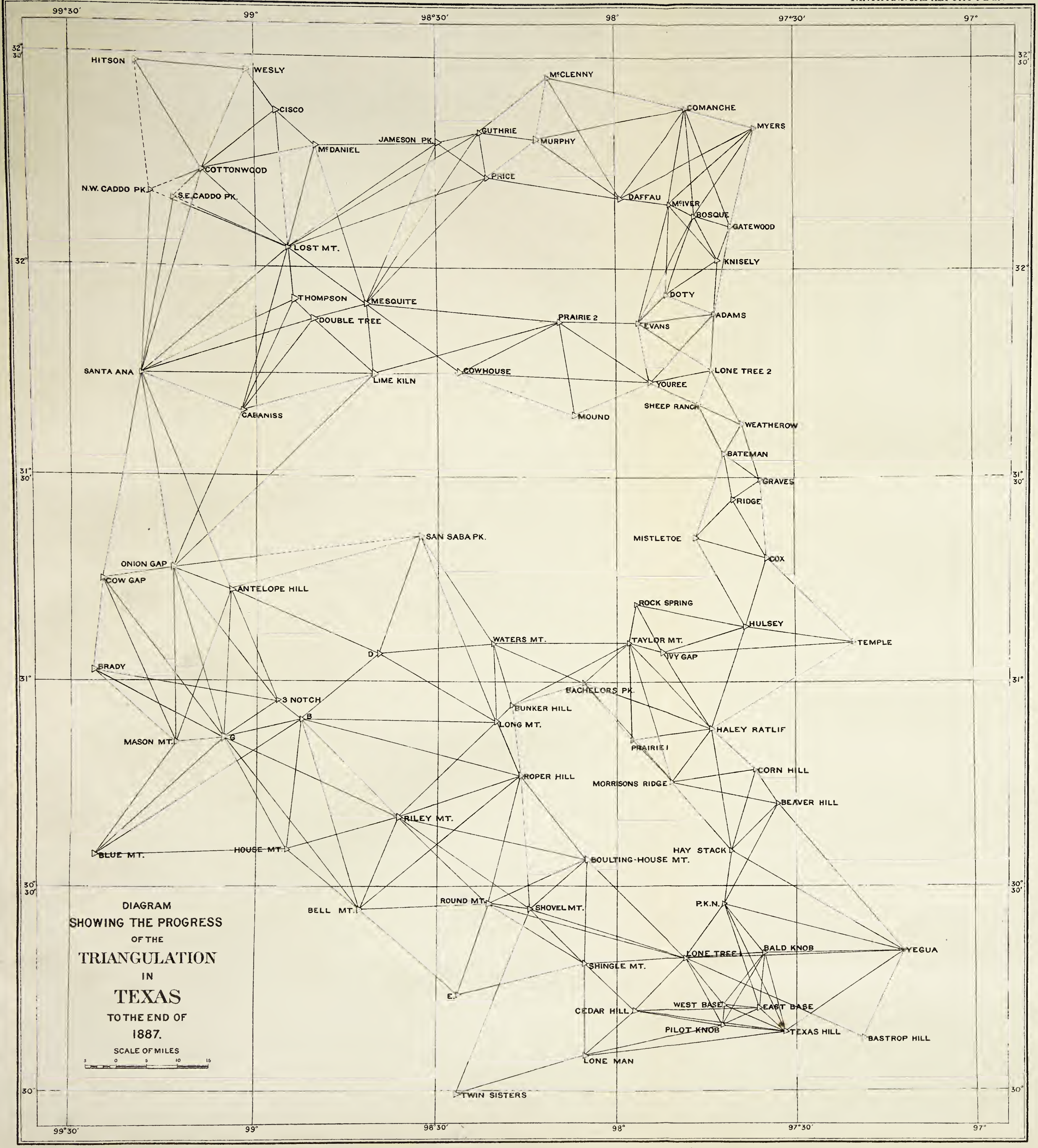



DIAGRAM
SHOWING THE PROGRESS
OF THE
TRIANGULATION
IN
TEXAS
TO THE END OF
1887.

SCALE OF MILES

5 0 5 10 15

Photo-Lith by A. HOEN & CO.

would permit. To this work were assigned a number of the best assistant topographers of the section, Messrs. R. C. McKinney, R. O. Gordon, R. L. Longstreet, D. C. Harrison, and J. W. Hays. Parts of the Abingdon, Bristol, Taylorsville, Roan Mountain and Asheville sheets were revised, and other large areas were examined with a view to revision if necessary.

Base barometric stations were maintained during the season at Lexington, Va., Richmond, Ky., Warrenton, Va., and Avondale, Ala. The observations taken by the Signal Service observers at Knoxville, Tenn., Lynchburgh, Va., Montgomery, Ala., and Atlanta, Ga., have been furnished through the courtesy of the Chief Signal Officer of the Army and used in the reduction of barometric altitudes.

In April, 1888, the work of surveying the great Dismal Swamp of eastern Virginia and the adjacent region was commenced. To this work were assigned Messrs. W. R. Atkinson, R. M. Towson, and E. G. Kennedy. It is proposed to publish the topographic work upon the scale of 1:125,000, and owing to the extremely low relief, the contour interval was set at five feet. Owing to the fact that great accuracy is required in the vertical element of the survey, it seemed desirable to have this surveyed by a separate operation and by means of the Y level. Mr. Towson was, therefore, furnished with a plane table and an odometer for traversing, for surveying the plan only, and his plane-table sheets were subsequently turned over to Mr. Atkinson, who ran lines with the Y level over them and put in the contours. This work was prosecuted continuously on this plan until the end of June, when the men were ordered to Washington, the season having become too far advanced for work to be prosecuted farther in this region. The area surveyed is estimated at 625 square miles.

Early in May Messrs. D. C. Harrison and R. McC. Michler were sent to survey that part of Maryland included in the Spottsylvania and Mount Vernon atlas sheets. This was surveyed with the plane table, using it as a traverse instrument, and was completed about the middle of June.

During May Messrs. Gordon and Hays were sent to the field for the purpose of continuing revision work, Mr. Hays upon the Mount Mitchell (N. C.) sheet, and Mr. Gordon upon the Greeneville (Tenn.) sheet.

In June Mr. A. E. Murlin was detailed for similar work upon the Estillville sheet. These men are making excellent progress.

During the month of June Messrs. M. Hackett, E. P. Gulliver, C. W. Goodlove, and R. B. Cameron were sent to the field in Maryland for the purpose of completing atlas sheet 39,76, where the close of the fiscal year finds them at work.

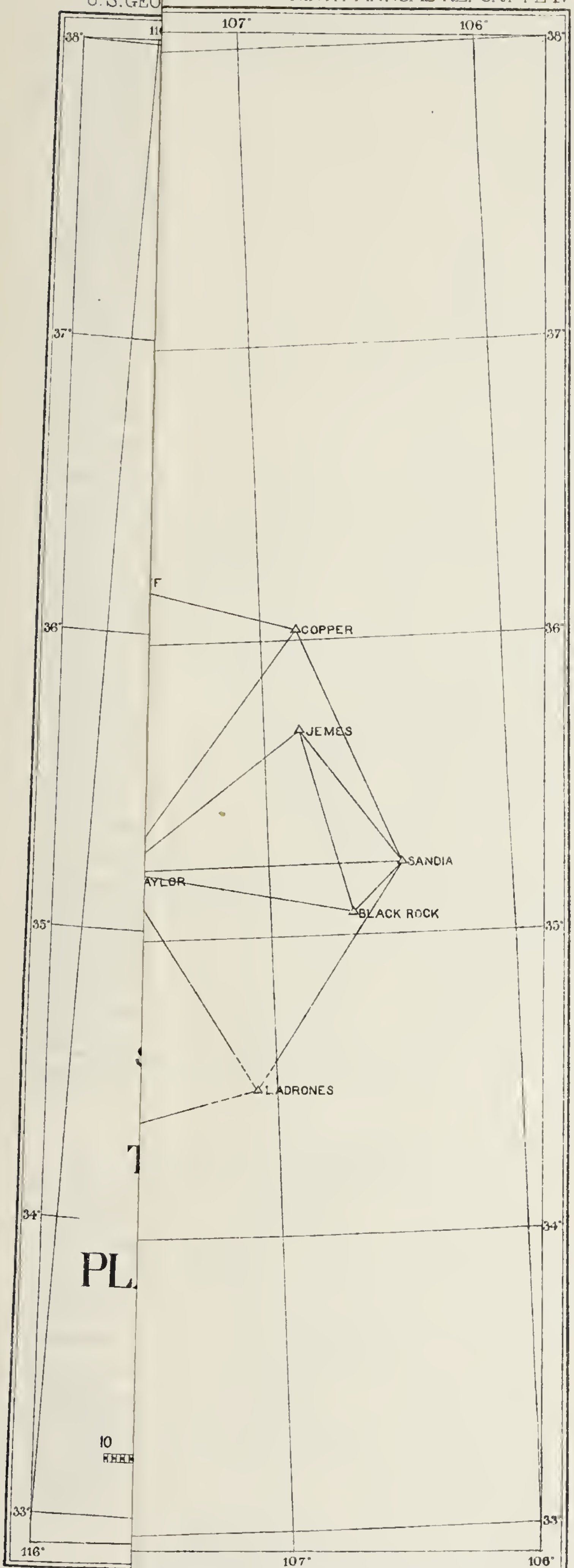
The entire area surveyed by the Appalachian section during the fiscal year is 16,525 square miles, exclusive of the areas revised.

CENTRAL SECTION.

This section has remained in charge of Mr. John H. Renshawe, geographer.

Work was continued in Missouri and Kansas and was commenced in Iowa, Arkansas, and Wisconsin. As in previous years, the work in Missouri has been carried on by Mr. H. L. Baldwin, topographer, to whom were assigned as assistants Messrs. W. H. Herron and C. W. Hawkins. They commenced work early in July. The area assigned them for survey consisted in the completion of the atlas sheets 39°–94° 30′, 39°–94°, 39°–93° 30′, 39°–93°, 39°–92° 30′, together with the entire area of atlas sheets 39°–92°, 39°–91° 30′, 39°–91°, 38° 30′–91° 30′, and 38° 30′–91°. This area, which includes a belt of variable width across the whole State, was completed by the middle of October. The party organization was then broken up, Mr. Hawkins was ordered to Washington, and Messrs. Baldwin and Herron were directed to proceed to southern Kansas and survey the atlas sheet 39°–97°. This was soon finished, and Messrs. Baldwin and Herron returned to Washington the latter part of October. The total area surveyed by this party during the season was 8,900 square miles.

The work in Arkansas was put in charge of Mr. S. S. Gannett, topographer, who was detailed from the Appalachian section for that purpose. A triangulation party was organized under his immediate direction, and a topographic party was organized under Mr. H. B. Blair, who was detailed from the Appalachian section. Mr. Gannett was given as assistant Mr. G. T. Hawkins, and to Mr. Blair were assigned Mr. Van H. Manning, jr., detailed from the northeastern section, B. W. Duke, and W. E. Lackland, the latter detailed from the Appalachian section. To this subsection was assigned the survey of the square degree limited between latitudes 34° 30′ and 35° 30′ and longitudes 93° 30′ and 94° 30′, an area of about 4,000 square miles. The work was designed for publication on the scale of 1:125,000, with contours fifty feet apart. Operations were commenced early in July. A base line about three miles long was measured on a tangent of the St. Louis and San Francisco Railway, in the eastern border of Indian Territory. The measurement was made with a three-hundred-foot steel tape, under a constant tension of twenty pounds, the tape being laid along the railroad ties and contacts being marked by a knife edge. The measurements were made on four successive nights, and the results, both as regards the total length and the three-hundred-foot sections, indicated that the measurement was amply good for the purpose for which it was made. An expansion was effected in the Ozark hills and triangulation carried over the area under survey, as shown upon the accompanying diagram, Pl. II. Connection was made with the astronomical station at Fort Smith, Ark. Fourteen stations were occupied and signals were erected upon two others, which were located but not occupied. Topographic

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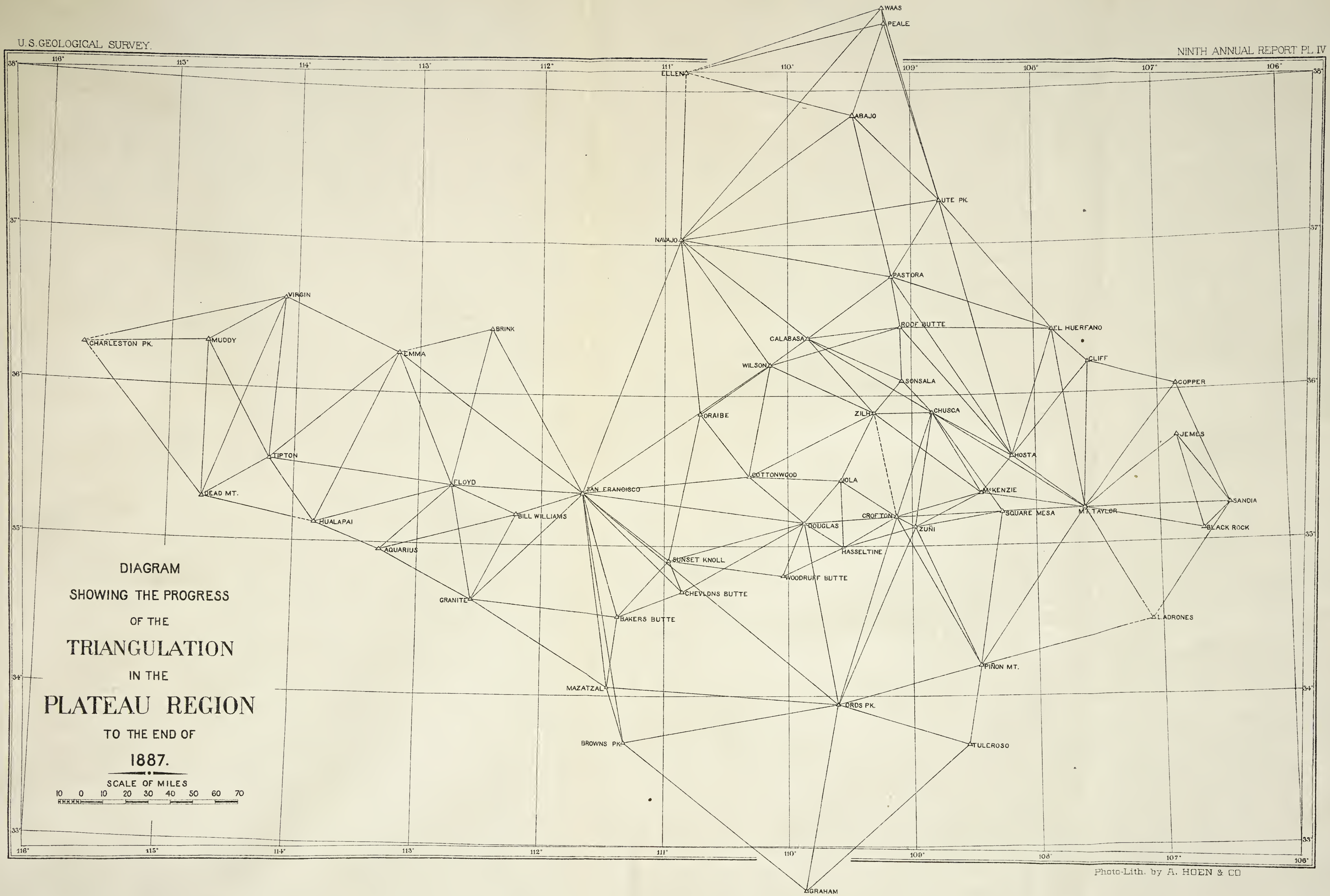
U.S. GEOLOGICAL SURVEY.

NINTH ANNUAL REPORT PL. IV

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work was carried forward through the season with great energy and good judgment, and the assigned area was completed early in November, when both parties disbanded and returned to Washington.

For the prosecution of work in Iowa Mr. W. J. Peters was selected, with Mr C. T. Reid as assistant. The area selected for survey comprised 30 minutes of latitude by 30 of longitude, lying between the parallels of 41° 30′ and 42° and the meridians of 91° 15′ and 91° 45′. The work was designed for publication upon the scale of 1:62,500, with contours twenty feet apart. The field sheets were made upon a scale of two inches to a mile, the scale of the township plats. Work was commenced early in July, utilizing the locations of township and section corners, roads, etc., as given by the land survey upon the ground. Heights were carried by the vertical circle of the alidade, sighting at natural objects, a method which was found to be very successful, both as regards accuracy and economy. Mr. Peters surveyed the area assigned him, comprising about 950 square miles, completing it early in November. For the control of this area a traverse line was run by him from the astronomical location at Rock Island, Ill., along the Chicago and Rock Island Railroad, to and across the area surveyed, measuring distances with a steel tape under a constant tension and directions by means of a ten-second theodolite. He adopted the azimuth determined at Rock Island and observed for azimuth at Iowa City, near the west end of the work.

During the past two years Prof. T. C. Chamberlin has had an assistant, Mr. T. M. Buell, engaged in topographic work in southern Wisconsin, mapping the glacial deposits of that region. Toward the close of the season, at his request, Mr. Renshawe personally undertook the extension of this survey to the westward, with a view to completing sheets for publication, the publication scale to be 1:62,500, i. e., the one-mile scale, and with twenty-foot contours. Mr. Renshawe was engaged upon this work until the latter part of November, and surveyed 136 square miles.

### WESTERN SECTION.

This section has remained under the charge of Prof. A. H. Thompson, chief geographer.

The only change in fields of work in this section consisted in the transfer of the force in Arizona to New Mexico.

*Texas subsection.*—The organization of this subsection has remained the same as in previous years. Mr. R. U. Goode, topographer, has remained in charge and has personally carried on the triangulation, while the two topographic parties have been in charge of Messrs. C. H. Fitch and H. S. Wallace, topographers. The parties took the field in July. No haste was employed in getting them at work, owing to the extreme heat, and it was not until the 1st of

August that work actually commenced. Mr. Goode, with his assistant, Mr. C. F. Urquhart, selected, built, and occupied during the season nineteen new stations in the primary triangulation, besides reoccupying three of the year before. The triangulation of this subsection is shown in the accompanying diagram, Pl. III.

Mr. Fitch, with Messrs. F. H. Thorpe, Robert Muldrow, and J. T. Jones, as assistants, surveyed an area of 2,000 square miles, completing the Brownwood and Coleman atlas sheets.

Mr. Wallace, with Messrs. Frank E. Gove, Lincoln Martin, and E. M. Hasbrouck, as assistants, surveyed 2,050 square miles, completing the Stevensville and Granbury atlas sheets, together with a part of the Glenrose sheet. The parties closed work and disbanded at the end of October and returned to Washington.

*New Mexico subsection.*—The party under Mr. A. P. Davis, which had formerly been at work in Arizona, was assigned to the survey of the following areas, lying in northwestern and central New Mexico, viz, the square degree 35°–106° and the area between the parallels of 36° and 36° 45′ and the meridians of 107° and 109°, consisting of the southern three-quarters of two atlas sheets, the northern quarter of which had been surveyed by the Hayden Survey in 1874–'75. Mr. Davis took the field early in July, with Messrs. R. H. Chapman, James E. Shelley, F. D. Ermentrout, and W. W. Davis as assistants. During most of the season this force was divided into three small parties, Mr. Davis himself carrying on primary triangulation, while a small party under Mr. Chapman undertook the southern area and another under Mr. W. W. Davis was assigned to the northern area. The latter was completed during the season. The work of the former party and of the triangulation was greatly interfered with by illness of the men. While the plans for the triangulation were carried out, only a small portion of the southern area, comprising perhaps a third of a square degree, was surveyed. The total area surveyed by this subsection was 7,200 square miles, and the parties disbanded at the close of October. The triangulation is shown on the accompanying diagram, Pl. IV.

*California subsection.*—The beginning of the year found Messrs. H. M. Wilson, A. F. Dunnington, and R. H. McKee in the field, engaged in carrying forward the triangulation over the area to be mapped during the season. This was completed during the favorable weather of the early summer. Three topographic parties were then organized, respectively under Messrs. Wilson, Dunnington, and McKee, the first of which was employed in surveying the unsurveyed area on the east of sheet 39°–120° 30′. The other two parties surveyed sheet 38° 30′–120° 30′, and a part of 38° 30′–121°. They closed work in the latter part of October. The total area surveyed by this subsection during the season is 1,436 square miles. The triangulation is shown on the accompanying diagram, Pl. V.

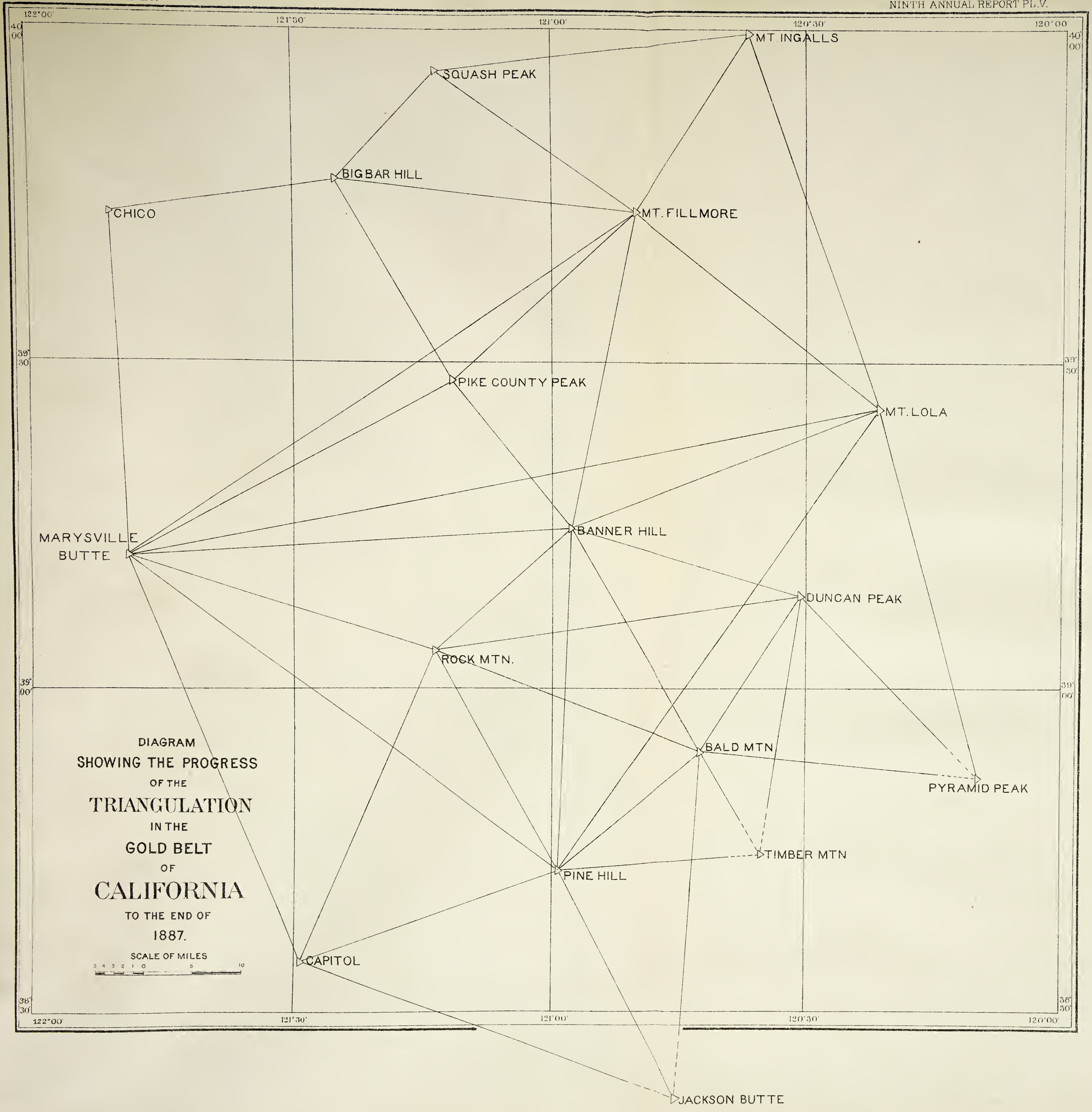
DIAGRAM
SHOWING THE PROGRESS
OF THE
TRIANGULATION
IN THE
GOLD BELT
OF
CALIFORNIA
TO THE END OF
1887.
SCALE OF MILES
5 4 3 2 1 0 5 10
MT INGALLS
SQUASH PEAK
BIG BAR HILL
CHICO
MT. FILLMORE
PIKE COUNTY PEAK
MT. LOLA
MARYSVILLE BUTTE
BANNER HILL
DUNCAN PEAK
ROCK MTN.
BALD MTN.
PYRAMID PEAK
TIMBER MTN
PINE HILL
CAPITOL
JACKSON BUTTE
122°00'
121°30'
121°00'
120°30'
120°00'
40° 00'
39° 30'
39° 00'
38° 30'

On the 1st of May of the present year Messrs. Wilson, Dunnington, and McKee were ordered again to the field for the purpose of extending the triangulation during the early part of the season while the atmospheric conditions were favorable. Reports received indicate the successful completion of the work.

*Oregon subsection.*—At the beginning of the fiscal year, Messrs. F. J. Knight and Eugene Ricksecker were in the field engaged in executing triangulation in advance of the topographic work. This having been completed, two topographic parties were organized under the charge of these two gentlemen. To Mr. Knight was assigned the survey of the atlas sheets 42°–123° and 42°–124°, and to Mr. Ricksecker the completion of sheets 42°–121° and 42°–122°. Work was carried on in this rugged mountain region until the middle of October, when the parties disbanded, having completed an area of 3,327 square miles. The accompanying diagram, Pl. VI, shows the progress of the triangulation.

Early in May of the present year work was resumed in this area for the purpose of extending the triangulation over the area to be surveyed during the current field season. Mr. W. T. Griswold, topographer, who was transferred from the Appalachian section, was placed in charge of the work and one of the parties, while the second party, owing to the resignation of Mr. Eugene Ricksecker, was put in charge of Mr. E. T. Perkins, assistant topographer. Mr. H. M. Wilson was also ordered up from the California subsection to assist temporarily in the work of the triangulation. Favorable atmospheric conditions have aided the work, and at the present date the triangulation has been extended sufficiently to control the area which will be surveyed this season.

*Montana subsection.*—The organization of this subsection has remained the same as during the previous year, being in charge of Mr. E. M. Douglas, topographer, and consisting of two topographic parties, respectively in charge of Messrs. Douglas and Frank Tweedy, topographers. To Mr. Douglas was assigned the work of carrying forward the triangulation for the entire area surveyed and the topographic survey of the unfinished portions of atlas sheets 46°–109° and 47°–110°. Mr. Tweedy was assigned to the survey of the unfinished portions of sheet 45°–110° and so much of 45°–112° as practicable. Work was commenced about the middle of July and carried on until the middle of October, when the parties disbanded. The area surveyed was 3,010 square miles.

Early in May of the present year Messrs. Douglas and Tweedy were ordered to the field, the former for the purpose of extending the triangulation over the area to be surveyed during the present season, and the latter for the prosecution of topographic work. At this date Mr. Douglas has practically completed the triangulation which will be required for the control of the season's work, and Mr. Tweedy has surveyed 1,000 square miles.

*Yellowstone Park.*—In connection with the geological work being prosecuted in the Yellowstone Park, it was found necessary to have some special maps made of the Hot Springs areas, and this work was assigned to Mr. Anton Karl, topographer, with Mr. J. R. Bien as assistant and the requisite number of rodmen. During the short field season Mr. Karl mapped the Upper and Lower Geyser Basins; the Norris Basin, and the group known as the Mammoth Hot Springs. During the winter Mr. Karl drew from these surveys eight maps, including, in addition to the maps of the geyser basins, certain still more special maps of parts of these basins.

During the winter months the topographers and their assistants were engaged in reducing the triangulation and completing the maps, and at the present date the work of the season of 1887 has been entirely completed and the maps have been prepared for the engraver.

In my last report a summary was presented of the control of the work of last year, together with some explanatory remarks. Similar data concerning the work of the past fiscal year are herewith presented in tabular form. It will be noted that the portion relating to the Massachusetts and New Jersey work covers the entire survey of those States.

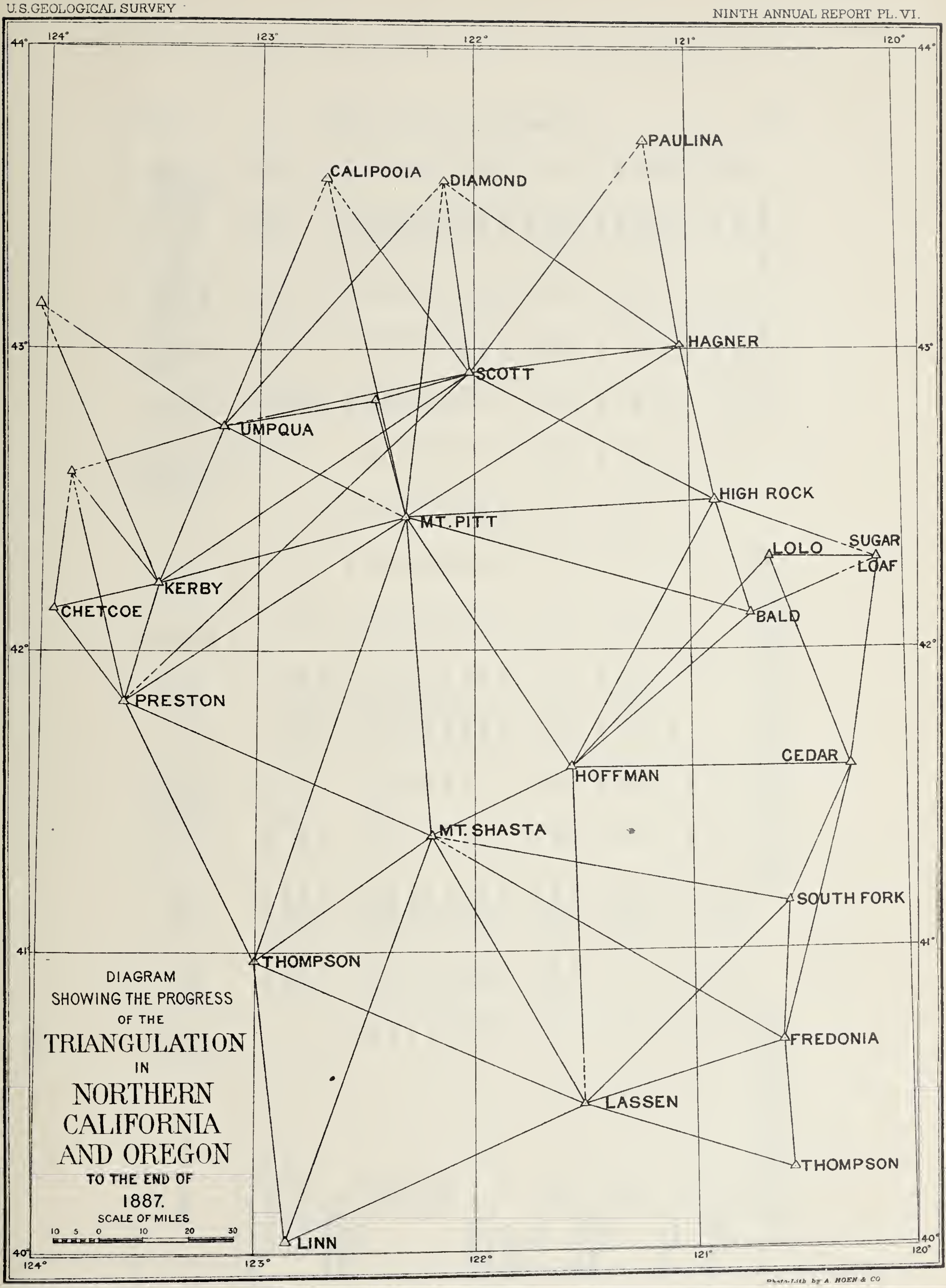


Photo-Lith by A. HOEN & CO

| Field of work. | Number of days' work. | Area, square miles. | Scale of publication | Intersection stations. | Points located by intersection. | Miles traversed. | Traverse stations. | Traverse stations per mile. | Stations per day. | Miles per day. | Intersection locations per square inch. | All locations per square inch. | Square miles per day per man. | Square inches per day per man. | Height measurements. | Heights per square inch. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Massachusetts: | | | | | | | | | | | | | | | | |
| Intersection work[1] | .... | 3,400 | 1: 62,500 | 3,123 | 17,846 | .... | .... | .... | .... | .... | 6.2 | 6.2 | 3.1 | 3.1 | 34,893 | 10.3 |
| Traverse work[1] | .... | 2,500 | 1: 62,500 | .... | .... | 5,615 | 46,524 | 8.3 | .... | .... | .... | 18.6 | 2.8 | 2.8 | 92,561 | 37.0 |
| Mixed work[1] | .... | 3,000 | 1: 62,500 | 900 | 3,718 | 6,767 | 31,708 | 4.7 | .... | .... | .... | 12.1 | .... | .... | .... | .... |
| New Jersey[2] | 7,000 | 7,900 | 1: 62,500 | 458 | .... | 19,721 | 215,255 | 10.9 | 75 | 6.9 | .... | 27.2 | .... | .... | .... | .... |
| Appalachian: | | | | | | | | | | | | | | | | |
| Party No. 1 | 240 | 2,100 | 1:125,000 | .... | .... | 2,227 | 20,569 | 9.2 | 86 | 9.3 | .... | 39.2 | 8.8 | 2.2 | 10,615 | 24.0 |
| No. 2 | 286 | 2,500 | 1:125,000 | 132 | 2,044 | 1,695 | 28,848 | 17.0 | 141 | 8.3 | 3.4 | 49.5 | 8.7 | 2.2 | 9,941 | 15.9 |
| No. 3 | 298 | 2,500 | 1:125,000 | 98 | 1,600 | 1,520 | 17,033 | 11.2 | 81 | 7.3 | 2.7 | 29.8 | 8.4 | 2.1 | 19,887 | 31.8 |
| No. 4 | 264 | 2,100 | 1:125,000 | 10 | 214 | 2,431 | 32,045 | 13.2 | 126 | 9.6 | 0.4 | 61.0 | 8.0 | 2.0 | 11,748 | 27.6 |
| No. 5 | 487 | 3,000 | 1:125,000 | 48 | 600 | 4,038 | 26,900 | 6.6 | 100 | 9.7 | 0.9 | 36.8 | 6.1 | 1.6 | 28,000 | 37.3 |
| No. 6 | 263 | 2,000 | 1:125,000 | 9 | 30 | 1,468 | 24,614 | 16.8 | 132 | 7.8 | 0.1 | 49.7 | 7.6 | 1.9 | 3,727 | 7.4 |
| Arkansas[3] | 201 | 4,000 | 1:125,000 | 25 | 707 | 1,650 | 8,485 | 5.1 | 48 | 9.4 | 0.7 | 9.2 | 20.0 | 5.0 | 8,500 | 8.5 |
| Missouri[3] | 204 | 7,900 | 1:125,000 | .... | .... | 6,095 | 11,596 | 1.9 | 57 | 29.8 | .... | 5.9 | 39.0 | 9.8 | 11,741 | 6.0 |
| Kansas[4] | 10 | 1,000 | 1:125,000 | .... | .... | 427 | 583 | 1.4 | 58 | 42.7 | .... | 2.4 | 100.0 | 25.0 | 583 | 2.3 |
| Texas: | | | | | | | | | | | | | | | | |
| Party No. 1 | 252 | 2,050 | 1:125,000 | 43 | 112 | 1,551 | 6,958 | 4.5 | 41 | 9.2 | 0.3 | 13.9 | 8.0 | 2.0 | 7,282 | 14.2 |
| No 2 | 177 | 2,000 | 1:125,000 | 42 | 191 | 915 | 5,179 | 5.7 | 44 | 7.8 | 0.5 | 10.8 | 11.0 | 2.8 | 5,864 | 11.7 |
| New Mexico[5] | 261 | 7,200 | 1:250,000 | 103 | 596 | 367 | 298 | 0.8 | .... | .... | 1.6 | 2.2 | 28.0 | 1.8 | 944 | 2.1 |
| California: | | | | | | | | | | | | | | | | |
| Party No. 1[5] | 72 | 465 | 1:125,000 | 48 | 402 | 364 | 2,246 | 6.2 | 51 | 8.3 | 3.9 | 23.2 | 6.5 | 1.6 | 2,685 | 23.2 |
| No. 2 | 159 | 570 | 1:125,000 | 48 | 648 | 470 | 3,820 | 8.1 | 36 | 4.4 | 4.9 | 31.8 | 3.6 | 0.9 | 4,550 | 31.5 |
| No. 3 | 190 | 401 | 1:125,000 | 55 | 996 | 637 | 5,341 | 8.4 | 39 | 4.7 | 10.5 | 63.9 | 2.1 | 0.5 | 8,663 | 86.6 |
| Oregon: | | | | | | | | | | | | | | | | |
| Party No. 1 | 101 | 1,680 | 1:250,000 | 56 | 1,625 | 367 | 1,290 | 3.5 | .... | .... | 16.0 | 28.3 | 16.6 | 1.0 | 1,700 | 16.2 |
| No. 2 | 44 | 1,647 | 1:250,000 | 68 | 522 | .... | .... | .... | .... | .... | 5.7 | 5.7 | 37.4 | 2.3 | 1,950 | 18.9 |
| Montana: | | | | | | | | | | | | | | | | |
| Party No. 1[5] | 48 | 1,360 | 1:250,000 | 71 | 116 | .... | .... | .... | .... | .... | 2.2 | 2.2 | 28.3 | 1.8 | 169 | 2.0 |
| No. 2 | 33 | 1,650 | 1:250,000 | 28 | 405 | .... | .... | .... | .... | .... | 2.3 | 2.3 | 50.0 | 3.1 | 616 | 6.0 |

[1] Entire experience in Massachusetts.
[2] Entire experience in New Jersey.
[3] Many secondary locations furnished by land surveys.
[4] All secondary locations made by land surveys.
[5] In part occupied with triangulation.

The table is presented not as a comparison of men, although doubtless the personal element has influence upon the results, but as a comparison of the effect upon output and amount of control exerted by the scale, the character of the country, and the methods employed. The intersection method has been used in preference to the traverse method wherever possible. Pure intersection work was possible over a large portion of the area of Massachusetts; a mixed system over a smaller area, in which there was much level or rolling timbered country; while over a still smaller proportion it was, owing to the low relief and the presence of woods, uneconomical to use it at all. The traverse method has been used throughout in the New Jersey survey. The hill country, where the intersection method might profitably have been employed, was surveyed before the U. S. Geological Survey assumed the conduct of the work. In the Appalachian region the relief of the country under survey ranges from the high mountains of Virginia down to the low plain near the estuary of the Potomac, all being well forested. Accordingly one sees in the work of the various parties differing proportions of intersection and traverse work. In Arkansas and Missouri, and particularly in Kansas, a considerable proportion of the secondary locations have been made by the surveys of the General Land Office, which, being properly utilized, reduce the amount of work necessary to be executed by the topographer.

The Texas country is rolling or broken with minor details, and partially timbered, with few natural points and comparatively few cultural features. New Mexico is mainly a broad desert plain, with few features, either natural or artificial. The California area consists of the western slope of the Sierra Nevada, a rugged mountain region, covered with forests, but fairly well settled. The Oregon region is also mountainous and forested, but sparsely settled. Party No. 1 of the Montana subsection was engaged in completing sheets upon the Great Plains, while No. 2 was in a region of high and rugged mountains.

These facts explain the differences in the methods used, the great variation in the amounts of intersection and of traverse work, and also, in a measure, the differences in the amount of control, as measured by the number of locations per square inch of map surface; it being borne in mind, as explained in my last report, that traverse locations are for various reasons of much less value for control than intersection locations, not only for horizontal but for vertical location as well. The second column of the table contains the number of days' work of one man, counting only those days actually spent in work by those engaged in surveying. The time of rodmen, barometer observers, and other similar assistants is not counted. A study of the columns relating to traverse work shows great variation in the number of stations per linear mile and of miles per day,

the two being to a great extent complementary, and indicating rudely the relative straightness of the roads along which most of the traverses are run.

The column of square inches of map surveyed per day per man is interesting, as showing the average output under varying conditions of country, of method, and of scale. The output is greater with the larger scales, showing the effect of transportation in reducing the rate of work upon the smaller scales. The close approach to equality of output of the various parties of the Appalachian section is worthy of remark. In the Arkansas, Missouri, and Kansas areas, especially the last, the output is increased greatly by the assistance rendered by the locations of the land surveys.

### SECTION OF TOPOGRAPHIC DRAWING.

During the year ten draughtsmen on the average have been in the employ of the Survey, under the direction of Mr. Harry King, chief draughtsman. Their work has been of a varied character, including as particular items the compilation of a map of the United States, the compilation of a map of New York, a map of Alabama, the preparation of a physical map of Massachusetts in one hundred feet contours, and the preparation of manuscript illustrations of various sorts.

### SECTION FOR THE REPAIR AND MANUFACTURE OF INSTRUMENTS.

The mechanician, Mr. Edward Kübel, with two assistants, has been engaged almost entirely throughout the year upon current repairs and the adjustment of the large number of instruments in use by the Survey. Indeed, his time has been so nearly taken up with this important work, that it has been found necessary to purchase nearly all new instruments. He has found time, however, to make six first-class telescopic alidades and twenty-four traverse plane tables with ruler alidades.

### ENGRAVING.

In my last annual report it was stated that contracts for engraving one hundred and twenty sheets of the General Topographic Atlas had been executed with Julius Bien & Co., of New York, and that a small edition of each sheet (250) had been printed. At the present date additional contracts have been made with the same firm for engraving one hundred sheets; and under these contracts forty-six sheets have been engraved, the plates delivered, and a similar small edition has been printed.

The following is a list of the sheets thus far engraved, which cover an area of about 285,000 square miles:

*List of atlas sheets engraved, July* 1, 1888.

| State or Territory. | Name of sheet. | Designation of sheet. | | Area covered. | Scale. | Contour interval. |
|---|---|---|---|---|---|---|
| | | *Lat.* ° ′ | *Long.* ° ′ | | | *Feet.* |
| Massachusetts | Greylock | 42 30 | 73 00 | $\frac{1}{16}$ degree | 1:62,500 | 40 |
| | Boston Bay | 42 15 | 70 45 | ....do | 1:62,500 | 20 |
| | Boston | 42 15 | 71 00 | ....do | 1:62,500 | 20 |
| | Worcester | 42 15 | 71 45 | ....do | 1:62,500 | 20 |
| | Northampton | 42 15 | 72 30 | ....do | 1:62,500 | 20 |
| | Duxbury | 42 00 | 70 30 | ....do | 1:62,500 | 20 |
| Massachusetts and Rhode Island | Fall River | 41 30 | 71 00 | ....do | 1:62,500 | 20 |
| New Jersey | Franklin | 41 00 | 74 30 | ....do | 1:62,500 | 20 |
| | Paterson | 40 45 | 74 00 | ....do | 1:62,500 | 20 |
| | Morristown | 40 45 | 74 15 | ....do | 1:62,500 | 20 |
| | Lake Hopatcong | 40 45 | 74 30 | ....do | 1:62,500 | 20 |
| | Hackettstown | 40 45 | 74 45 | ....do | 1:62,500 | 20 |
| | Plainfield | 40 30 | 74 15 | ....do | 1:62,500 | 20 |
| | Sandy Hook | 40 15 | 74 00 | ....do | 1:62,500 | 10 |
| | New Brunswick | 40 15 | 74 15 | ....do | 1:62,500 | 10 |
| | Princeton | 40 15 | 74 30 | ....do | 1:62,500 | 10 |
| | Asbury Park | 40 00 | 74 00 | ....do | 1:62,500 | 10 |
| | Cassville | 40 00 | 74 15 | ....do | 1:62,500 | 10 |
| | Bordentown | 40 00 | 74 30 | ....do | 1:62,500 | 10 |
| | Barnegat | 39 45 | 74 00 | ....do | 1:62,500 | 10 |
| | Whitings | 39 45 | 74 15 | ....do | 1:62,500 | 10 |
| | Pemberton | 39 45 | 74 30 | ....do | 1:62,500 | 10 |
| | Mount Holly | 39 45 | 74 45 | ....do | 1:62,500 | 10 |
| | Long Beach | 39 30 | 74 00 | ....do | 1:62,500 | 10 |
| | Little Egg Harbor | 39 30 | 74 15 | ....do | 1:62,500 | 10 |
| | Atlantic City | 39 15 | 74 15 | ....do | 1:62,500 | 10 |
| | Sea Isle | 39 00 | 74 30 | ....do | 1;62,500 | 10 |
| | Dennisville | 39 00 | 74 45 | ....do | 1:62,500 | 10 |
| | Cape May | 38 45 | 74 45 | ....do | 1:62,500 | 10 |
| Maryland, District of Columbia, and Virginia. | East Washington. | 38 45 | 76 45 | ....do | 1:62,500 | 20 |
| | West Washington. | 38 45 | 77 00 | ....do | 1:62,500 | 20 |
| West Virginia | St. George | 39 00 | 79 30 | $\frac{1}{4}$ degree | 1:125,000 | 100 |
| | Raleigh | 37 30 | 81 00 | ....do | 1:125,000 | 100 |
| | Oceana | 37 30 | 81 30 | ....do | 1:125,000 | 100 |
| Maryland, Virginia, and West Virginia. | Romney | 39 00 | 78 30 | ....do | 1:125,000 | 100 |
| Maryland and West Virginia | Piedmont | 39 00 | 79 00 | ....do | 1:125,000 | 100 |
| West Virginia and Virginia | Winchester | 39 00 | 78 00 | ....do | 1:125,000 | 100 |
| | Pocahontas | 37 00 | 81 00 | ....do | 1:125,000 | 100 |
| | Tazewell | 37 00 | 81 30 | ....do | 1:125,000 | 100 |
| West Virginia, Virginia, and Kentucky. | Warfield | 37 30 | 82 00 | ....do | 1:125,000 | 100 |
| Kentucky | Prestonburgh | 37 30 | 82 30 | ....do | 1:125,000 | 100 |
| Virginia and Kentucky | Whitesburgh | 37 00 | 82 30 | ....do | 1:125,000 | 100 |
| | Grundy | 37 00 | 82 00 | ....do | 1:125,000 | 100 |
| Kentucky, Virginia, and Tennessee. | Jonesville | 36 30 | 83 00 | ....do | 1:125,000 | 100 |
| | Cumberland Gap. | 36 30 | 83 30 | ....do | 1:125,000 | 100 |
| | Estillville | 36 30 | 82 30 | ....do | 1:125,000 | 100 |
| Virginia and Tennessee | Bristol | 36 30 | 82 00 | ....do | 1:125,000 | 100 |
| Virginia, Tennessee, and North Carolina. | Abingdon | 36 30 | 81 30 | ....do | 1:125,000 | 100 |
| North Carolina | Cowee | 35 00 | 83 00 | ....do | 1:125,000 | 100 |

*List of atlas sheets engraved, July* 1, 1886—Continued.

| State or Territory. | Name of sheet. | Designation of sheet. | | Area covered. | Scale. | Contour interval. |
|---|---|---|---|---|---|---|
| | | *Lat.* ° ′ | *Long.* ° ′ | | | *Feet.* |
| North Carolina and Tennessee.... | Roan Mountain... | 36 00 | 82 00 | ¼ degree. | 1:125,000 | 100 |
| | Greeneville....... | 36 00 | 82 30 | ....do..... | 1:125,000 | 100 |
| | Asheville.......... | 35 30 | 82 30 | ....do..... | 1:125,000 | 100 |
| | Mount Guyot..... | 35 30 | 83 00 | ....do..... | 1:125,000 | 100 |
| | Knoxville......... | 35 30 | 83 30 | ....do..... | 1:125,000 | 100 |
| | Nantahalah ..... | 35 00 | 83 30 | ....do.... | 1:125,000 | 100 |
| | Murphy .......... | 35 00 | 84 00 | ....do..... | 1:125,000 | 100 |
| Tennessee.. ...................... | Morristown....... | 36 00 | 83 00 | ....do..... | 1:125,000 | 100 |
| | Maynardville..... | 36 00 | 83 30 | ....do..... | 1:125,000 | 100 |
| | Loudon.......... | 35 30 | 84 00 | ....do..... | 1:125,000 | 100 |
| | Kingston.......... | 35 30 | 84 30 | ....do..... | 1:125.000 | 100 |
| | Cleveland ........ | 35 00 | 84 30 | ....do..... | 1:125,000 | 100 |
| South Carolina and Georgia....... | Walhalla ......... | 34 30 | 83 00 | ....do..... | 1:125,000 | 100 |
| Georgia ........................... | Dahlonega........ | 34 30 | 83 30 | ....do..... | 1:125,000 | 100 |
| Georgia and Alabama.............. | Ringgold......... | 34 30 | 85 00 | ....do..... | 1:125,000 | 100 |
| | Rome............. | 34 00 | 85 00 | ....do .... | 1:125,000 | 100 |
| | Stevenson ........ | 34 30 | 85 30 | ....do..... | 1:125,000 | 100 |
| Alabama. .......................... | Fort Payne.. .... | 34 00 | 85 30 | ....do..... | 1:125,000 | 100 |
| | Scottsborough.... | 34 30 | 86 00 | ....do..... | 1:125,000 | 100 |
| | Huntsville........ | 34 30 | 86 30 | ....do . | 1:125,000 | 100 |
| Missouri.......................... | Boonville......... | 38 30 | 92 30 | do..... | 1:125,000 | 50 |
| | Versailles... ..... | 38 00 | 92 30 | ....do..... | 1:125.000 | 50 |
| | Jefferson City.... | 38 30 | 92 00 | ....do..... | 1:125,000 | 50 |
| | Tuscumbia ....... | 38 00 | 92 00 | ....do..... | 1:125,000 | 50 |
| | Sedalia. .......... | 38 30 | 93 00 | .... do..... | 1:125,000 | 50 |
| | Warrensburgh.... | 38 30 | 93 30 | ....do..... | 1:125,000 | 50 |
| | Harrisonville..... | 38 30 | 94 00 | ....do..... | 1:125,000 | 50 |
| | Warsaw.... ...... | 38 00 | 93 00 | ....do..... | 1:125,000 | 50 |
| | Clinton ........... | 38 00 | 93 30 | ....do..... | 1:125,000 | 50 |
| | Butler ............ | 38 00 | 94 00 | .... do..... | 1:125,000 | 50 |
| | Bolivar.. ......... | 37 30 | 93 00 | ....do..... | 1:125,000 | 50 |
| | Stockton.......... | 37 30 | 93 30 | ....do..... | 1:125,000 | 50 |
| | Nevada........... | 37 30 | 94 00 | ....do..... | 1:125,000 | 50 |
| | Springfield. ..... | 37 00 | 93 00 | ....do..... | 1:125,000 | 50 |
| | Greenfield ...... .. | 37 00 | 93 30 | ....do..... | 1:125,000 | 50 |
| | Carthage.... .... | 37 00 | 94 00 | ....do..... | 1:125,000 | 50 |
| Missouri and Kansas........ ...... | Olathe............ | 38 30 | 94 30 | ....do..... | 1:125,000 | 50 |
| | Mound City....... | 38 00 | 94 30 | ....do..... | 1:125,000 | 50 |
| | Fort Scott........ | 37 30 | 94 30 | .... do..... | 1:125,000 | 50 |
| | Joplin.... ........ | 37 00 | 94 30 | ....do..... | 1:125,000 | 50 |
| Kansas .......................... | Iola............... | 37 30 | 95 00 | ....do..... | 1:125,000 | 50 |
| | Fredonia.......... | 37 30 | 95 30 | ....do..... | 1:125,000 | 50 |
| | Independence..... | 37 00 | 95 30 | ....do..... | 1:125,000 | 50 |
| | Parsons ...... ..... | 37 00 | 95 00 | ....do.... | 1:125,000 | 50 |
| | Oskaloosa........ | 39 00 | 95 00 | ....do..... | 1:125,000 | 50 |
| | Emporia.......... | 38 00 | 96 00 | ....do..... | 1:125,000 | 50 |
| | Garnett........... | 38 00 | 95 00 | ....do..... | 1:125,000 | 50 |
| | Eureka........... | 37 30 | 96 00 | ....do..... | 1:125,000 | 50 |
| | El Dorado.... .... | 37 30 | 96 30 | .... do..... | 1:125,000 | 50 |
| | Hiawatha......... | 39 30 | 95 30 | ....do..... | 1:125.000 | 50 |
| Texas.............................. | San Saba......... | 31 00 | 98 30 | ....do..... | 1:125,000 | 50 |
| | Lampasas ........ | 31 00 | 98 00 | ... do..... | 1:125,000 | 50 |

*List of atlas sheets engraved, July 1, 1886*—Continued.

| State or Territory. | Name of sheet. | Designation of sheet. | | Area covered. | Scale. | Contour interval. |
|---|---|---|---|---|---|---|
| | | *Lat.* ° ′ | *Long.* ° ′ | | | *Feet.* |
| Texas | Taylor | 30 30 | 97 00 | ¼ degree. | 1: 125,000 | 50 |
| | Georgetown | 30 30 | 97 30 | ....do | 1: 125,000 | 50 |
| | Burnet | 30 30 | 98 00 | ....do | 1: 125,000 | 50 |
| | Llano | 30 30 | 98 30 | ....do | 1: 125,000 | 50 |
| | Mason | 30 30 | 99 00 | ....do | 1: 125,000 | 50 |
| | Bastrop | 30 00 | 97 00 | ....do | 1: 125,000 | 50 |
| | Austin | 30 00 | 97 30 | ....do | 1: 125,000 | 50 |
| | Blanco | 30 00 | 98 00 | ....do | 1: 125,000 | 50 |
| | Fredericksburgh | 30 00 | 98 30 | ....do | 1: 125,000 | 50 |
| | Kerrville | 30 00 | 99 00 | ....do | 1: 125,000 | 50 |
| Yellowstone National Park and Wyoming. | Gallatin | 44 30 | 110 30 | ....do | 1: 125,000 | 100 |
| | Cañon | 44 30 | 110 00 | ....do | 1: 125,000 | 100 |
| | Shoshone | 44 00 | 110 30 | ....do | 1: 125,000 | 100 |
| | Lake | 44 00 | 110 00 | ....do | 1: 125,000 | 100 |
| California | Marysville | 39 00 | 121 30 | do | 1: 125,000 | 100 |
| | Nevada City | 39 00 | 121 00 | ....do | 1: 125,000 | 100 |
| | Alturas | 41 00 | 120 00 | Degree. | 1: 250,000 | 200 |
| | Modoc Lava Bed | 41 00 | 121 00 | ....do | 1: 250,000 | 200 |
| | Shasta | 41 00 | 122 00 | ....do | 1: 250,000 | 200 |
| | Red Bluff | 40 00 | 122 00 | ....do | 1: 250,000 | 200 |
| | Lassen Peak | 40 00 | 121 00 | ....do | 1: 250,000 | 200 |
| | Honey Lake | 40 00 | 120 00 | ....do | 1: 250.000 | 200 |
| Montana | Great Falls | 47 00 | 111 00 | ....do | 1: 250,000 | 200 |
| | Fort Logan | 46 00 | 111 00 | ....do | 1: 250,000 | 200 |
| | Little Belt Mount. | 46 00 | 110 00 | ....do | 1: 250,000 | 200 |
| | Three Forks | 45 00 | 111 00 | ....do | 1: 250,000 | 200 |
| Nevada | Paradise | 41 00 | 117 00 | ....do | 1: 250,000 | 200 |
| | Disaster | 41 00 | 118 00 | ....do | 1: 250,000 | 200 |
| | Long Valley | 41 00 | 119 00 | ....do | 1: 250,000 | 200 |
| | Granite Range | 40 00 | 119 00 | ....do | 1: 250,000 | 200 |
| Utah | Tooele Valley | 40 00 | 112 00 | ....do | 1: 250 000 | 250 |
| | Salt Lake | 40 00 | 111 00 | ....do | 1: 250,000 | 250 |
| | Uinta | 40 00 | 110 00 | ....do | 1: 250,000 | 250 |
| | Ashley | 40 00 | 109 00 | ....do | 1: 250,000 | 250 |
| | Sevier Desert | 39 00 | 112 00 | ... do | 1: 250,000 | 250 |
| | Manti | 39 00 | 111 00 | ....do | 1: 250,000 | 250 |
| | Price River | 39 00 | 110 00 | ....do | 1: 250,000 | 250 |
| | East Tavaputs | 39 00 | 109 00 | ....do | 1: 250,000 | 250 |
| | Beaver | 38 00 | 112 00 | ....do | 1: 250,000 | 250 |
| | Fish Lake | 38 00 | 111 00 | ....do | 1: 250,000 | 250 |
| | San Rafael | 38 00 | 110 00 | ....do | 1: 250,000 | 250 |
| | Sierra La Sal | 38 00 | 109 00 | ....do | 1: 250,000 | 250 |
| | St. George | 37 00 | 113 00 | ....do | 1: 250,000 | 250 |
| | Kanab | 37 00 | 112 00 | ....do | 1: 250,000 | 250 |
| | Escalante | 37 00 | 111 00 | ...do | 1: 250,000 | 250 |
| | Henry Mountain | 37 00 | 110 00 | ....do | 1: 250,000 | 250 |
| | Abajo | 37 00 | 109 00 | ....do | 1: 250,000 | 250 |
| New Mexico | Mount Taylor | 35 00 | 107 00 | ....do | 1: 250,000 | 200 |
| | Wingate | 35 00 | 108 00 | ....do | 1: 250,000 | 200 |
| Utah and Nevada | Pioche | 37 00 | 114 00 | ....do | 1: 250,000 | 250 |
| Arizona and Nevada | St. Thomas | 36 00 | 114 00 | ....do | 1: 250,000 | 250 |
| Arizona, Nevada, and California | Camp Mojave | 35 00 | 114 00 | ....do | 1: 250,000 | 250 |

*List of atlas sheets engraved, July* 1, 1888—Continued.

| State or Territory. | Name of sheet. | Designation of sheet. | | Area covered. | Scale. | Contour interval. |
|---|---|---|---|---|---|---|
| | | Lat. | Long. | | | |
| | | ° ′ | ° ′ | | | Feet. |
| Arizona | Mount Trumbull | 36 00 | 113 00 | Degree | 1:250,000 | 250 |
| | Kaibab | 36 00 | 112 00 | do | 1:250,000 | 250 |
| | Echo Cliffs | 36 00 | 111 00 | do | 1:250,000 | 250 |
| | Marsh Pass | 36 00 | 110 00 | do | 1:250,000 | 200 |
| | Diamond Creek | 35 00 | 113 00 | do | 1:250,000 | 250 |
| | Chino | 35 00 | 112 00 | do | 1:250,000 | 250 |
| | San Francisco Mountain. | 35 00 | 111 00 | do | 1:250,000 | 250 |
| | Tusayan | 35 00 | 110 00 | do | 1:250,000 | 200 |
| | Prescott | 34 00 | 112 00 | do | 1:250,000 | 200 |
| | Verde | 34 00 | 111 00 | do | 1:250,000 | 200 |
| | Holbrook | 34 00 | 110 00 | do | 1:250,000 | 200 |
| Arizona and New Mexico | Cañon de Chelly | 36 00 | 109 00 | do | 1:250,000 | 200 |
| | Fort Defiance | 35 00 | 109 00 | do | 1:250,000 | 200 |
| | St. Johns | 34 00 | 109 00 | do | 1:250,000 | 200 |

There are in the office ready for the engraver one hundred and forty-one sheets, including those now under contract, but not yet engraved. These sheets cover an area of 108,000 square miles. Fifty-four of these sheets are under contract for engraving. The remaining eighty-seven await contract. These one hundred and forty-one sheets are distributed as follows:

| | | | |
|---|---|---|---|
| New Jersey | 12 | Arkansas | 4 |
| Massachusetts | 43 | Texas | 8 |
| Maryland | 1 | Colorado | 2 |
| Appalachian region | 36 | New Mexico | 2 |
| Wisconsin | 2 | California | 2 |
| Missouri | 10 | Oregon | 1 |
| Kansas | 15 | Montana | 3 |

I have the honor to transmit herewith the report of Mr. R. S. Woodward, geographer, in charge of the astronomic and computing section.

Very respectfully submitted'

HENRY GANNETT,
*Geologist in Charge.*

HON. J. W. POWELL,
*Director U. S. Geological Survey Washington, D. C.*

## Report of Mr. R. S. Woodward to Chief of Division of Geography.

Sir: In compliance with the instructions of the Director of the Survey, I have the honor to submit the following report on work done during the year ending June 30, 1888:

The work done for your division during the year may be briefly designated under three heads, namely: (*a*) That involved in numerical computations; (*b*) That involved in the collection, collation, and arrangement of geographical positions for ready reference; and (*c*) That involved in assistance rendered to the geographers and topographers of the Survey in the technical details of their work.

(*a*) Of the numerous computations made it will suffice to mention some of the more important.

During the month of July, 1887, the net results of the secondary system of triangulation in Massachusetts, measured by Mr. R. U. Goode during May and June of that year, were computed. This work embraced a complete reduction from the field notes, an approximate adjustment of the triangles, and the derivation of the latitudes and longitudes of the sixteen points of the system.

Two numerical tables for determining altitudes from telemeter measures were computed and printed for the use of topographers in the field.

In order to meet the frequent requests of geographers and topographers for information relative to the determination of azimuth, certain practical memoranda were prepared for their use; and tables giving the local mean times of culmination and elongation and the azimuths at elongation of Polaris, for intervals of a degree in latitude between 30° and 45° and for the field season, were computed. Such tables will be kept available hereafter in manuscript, so that the data for any special locality can be speedily supplied.

The desirability of publishing our tables of co-ordinates for map projections, now in manuscript, was made apparent by their constant use during the year. At your suggestion, therefore, they were revised and enlarged, and are now nearly ready for the press. With the accompanying explanatory text, they will embrace about one hundred octavo pages.

(*b*) Attention was constantly paid to keeping the list of geographical positions of points within the United States as complete as possible and always available for use. Upwards of three thousand new positions were added to the list during the year. These were obtained chiefly from the reports of the U. S. Coast and Geodetic Survey and the New York State survey. The list now embraces over ten thousand entries.

(*c*) A considerable portion of my time, especially during the winter season, is now occupied either in consultation with members of the division concerning the methods and formulas most advantageous

for computations, the mathematical theory of instruments, observations, etc., or in supplying them with data for their work. To meet this demand for information, such collections of technical works, notes, and investigations as I have made previous to and during my connection with the Survey are kept at the office, accessible to any member of the Survey.

I was assisted continuously during the year by Mr. B. C. Washington, jr., who made the greater portion of the current computations and discharged all the clerical duties in my work.

During the months of May and June Mr. S. S. Gannett was assigned to my assistance. He made the bulk of the computations required in the revision and extension of the tables of co-ordinates for map projections mentioned under *a*, above.

Very respectfully, your obedient servant,

R. S. WOODWARD,
*Geographer.*

Mr. HENRY GANNETT,
*Geologist in Charge of Geography.*

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## REPORT OF MR. R. S. WOODWARD.

MATHEMATICAL DIVISION,
*Washington, D. C., July* 1, 1888.

SIR: I have the honor to submit the following report concerning investigations of geological problems made by me during the year ending June 30, 1888:

As stated in my report for the year ending June 30, 1887, much of the work assigned to me is directly contributory to the work of the Division of Geography. For an account of work done for this division during the present year reference may be made here to the report of Mr. H. Gannett, geologist in charge of geography.

Many of the questions involving mathematical or physical considerations referred to me during the year were such as required only temporary examination or brief applications of principles already established. Although the aggregate amount of work done on these questions was not inconsiderable, it will suffice here to mention those only on which formal papers were prepared. At the request of Mr. G. K. Gilbert, two brief appendices to his memoir on Lake Bonneville were written. The first of these refers to the form and position of equipotential or level surfaces in a lake basin, and is based on my investigations given in Bulletin 48 of the Survey publications. The second paper deals with the volumetric expansion of the earth's crust, due to the diffusion of heat by conduction from the surface downward, and depends on the researches concerning the laws and effects of terrestrial heat mentioned below.

Of the questions requiring more elaborate treatment which were under investigation during the year the following three occupied my attention, chiefly in such intervals of time as were available, namely: (*a*) The laws of diffusion of heat by conduction in homogeneous spherical masses and the resulting mechanical effects; (*b*) The laws of diffusion of heat by conduction in homogeneous rectangular masses of any dimensions; (*c*) The possible laws of arrangement of density in the earth's mass under the assumption that the density increases continually from the surface towards the center.

(*a*) The problem of a cooling sphere is not new. It was very thoroughly discussed in its purely mathematical features by Fourier and Poisson, the pioneers in the theory of heat, and has been much studied by mathematicians of later date. Able and elaborate as their work is, however, it is not well adapted to the needs of practical applications; it does not enable one to trace readily and accurately all the phenomena of cooling throughout their entire history. My investigations of this problem were necessarily made partly with a view to supplying the defect just named. As a result two papers were published, by your permission, during the year.[1] These deal chiefly with purely technical considerations, and an account of their contents would be out of place here. It will suffice to state that they furnish a satisfactory basis for the study of the phenomena attending the secular cooling of the earth.

In the study just mentioned considerable progress was made during the year, and a paper comprising the results attained is now nearly ready for publication. A brief summary of the contents of this paper is the following:

The data necessary for calculation of the secular cooling of the earth; the age of the earth, derivable from those data; the distribution of the isogeotherms; the rate of increase of under-ground temperature and its variation with the time; the radial and cubical contraction; the rational theory of crumpling in the crust; the stratum of no strain; the volumetric amount of crumpling and its dependence on the initial temperature and elapsed time.

(*b*) The consideration of many physical questions requires an intimate knowledge of the laws of diffusion of heat in rectangular masses; and since the publication of the above-named papers on a cooling sphere I have received a number of requests for a similar practical treatment of a cooling bar or rectangular mass. My studies of this subject, from the experimental as well as the theoretical side, began fifteen years ago, when engaged in comparing standards of length on the U. S. Lake Survey. Recently I have revised and extended my theoretical investigations, and have now ready for pub-

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[1] On the Free Cooling of a Homogeneous Sphere; Annals of Mathematics, vol. 3, No. 3, pp. 75–88. On the Conditioned Cooling and Cubical Contraction of a Homogenous Sphere; Annals of Mathematics, vol. 3, No. 5, pp. 129–144.

lication a paper embodying the practical results. It is believed that these will be useful in enabling us to determine the thermal conductivities of rocks, either from such experiments as have been made or from such as may be easily devised.

(*c*) One of the most interesting and obscure questions of geophysics is the law of arrangement of density within the earth's crust. If we assume that the density increases continuously from the surface downwards, the law of increase is subject to certain rather narrow limitations, dependent on the known properties of the earth, namely, its surface shape, its surface density, its mean density, and its constant of precession. I have begun an investigation whose object is to determine what those limitations are, and it is expected that the work will be completed during the coming year.

Very respectfully, your obedient servant,

R. S. WOODWARD,
*Geographer in Charge.*

Hon. J. W. POWELL,
*Director U. S. Geological Survey, Washington, D. C.*

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## REPORT OF PROF. N. S. SHALER.

ATLANTIC COAST DIVISION,
*Cambridge, Mass., July* 1, 1888.

SIR: I have the honor to submit the following administrative report concerning the operations of the Survey under my charge during the fiscal year ending June 30, 1888:

The month of July was devoted to the task of completing certain details of the work on the island of Mount Desert, Maine, a memoir on which formed a part of the Eighth Annual Report of the Director.

I then spent some time in searching for evidence of elevated sea margins in Massachusetts and eastern New York, similar to those described in the above-named memoir, selecting first for these studies the peak of Wachusett, in Worcester County, Mass. I examined the slopes of this mountain for evidences of wave action. At heights of from 1,500 to 2,000 feet on the eastern, southern, and western versants of the mountains the cliffs exhibit some indications of what may prove on further study to be marine erosion.

From Wachusett I proceeded to the Catskill district in New York, and made a reconnaissance of the eastern face of those elevations for a distance of about twenty miles south of the town of Palenville. On this escarpment I found at several points, at a height of from 2,000 to 2,300 feet above the sea, phenomena which I can not at present explain save by the hypothesis that the ocean waves acted against the face of the cliff since the close of the glacial period. At about 2,200 feet above the sea there are some cavities having the

general form of marine caves which are evidently not due to the ordinary decay of the rock. At heights of from 1,600 to 2,000 feet there are accumulations of shingly material apparently worn and arranged in a stratified manner by wave action.

In August and September I made an extended journey through the swamp districts of Michigan, Wisconsin, Minnesota, and Dakota. The substantial results of this journey were to afford a basis for the classification of the swamps in the Northwest and a foundation on which to rest an approximate estimate as to the total area. It appears that the inundated lands of this region cover a surface of at least 20,000 square miles; that these lands are in the main drainable without excessive cost; and furthermore, as is shown by some small experiments in winning such lands to agriculture, that the soils which they yield are of excellent quality.

My time for the remainder of the autumn was devoted to certain studies in eastern Massachusetts and Rhode Island. With the help of Mr. R. S. Tarr, field assistant, I had begun in June of the preceding fiscal year a study of the island of Cape Ann and the adjacent portions of the main-land of Massachusetts. The aim of the inquiry was in the main to ascertain the geological conditions of the hornblendic granite of that district, together with the circumstances connected with the dikes which are extensively intruded in the mass of that rock. The region affords peculiar advantages for the study of the phenomena of jointing and rifting, questions which are of great interest to quarrymen. The results of this inquiry are presented in a memoir published in this volume.

With the help of Mr. August F. Foerste, field assistant, I have worked up the details of my discoveries of certain fossiliferous localities in the Middle Cambrian slates of North Attleborough, Mass. Twenty-three species of fossils have already been obtained from these beds, and identified, described, and figured.

As is noted in my memoir "On the Geology of Martha's Vineyard," in the Seventh Annual Report of the Director, I found on that island an interesting locality of apparently Cretaceous fossils. With the assistance of Mr. Foerste I made a collection of the fossils from this point. The result has been to establish the existence of lower Cretaceous rocks in this field.

With the aid of Messrs. T. W. Harris, W. Beals, and G. T. Quinby, volunteer assistants in the Survey, I have been able to continue the inquiries on the Narragansett Basin. It appears that rocks apparently of Carboniferous age, situated between Point Judith and Providence, R. I., representing a thickness of section of some thousands of feet, have undergone much metamorphism. Elsewhere in the Narragansett field these Carboniferous deposits have been very slightly altered since the time of their formation.

On the 26th of December, 1887, I started on an expedition to Flor-

ida. I was engaged in this journey until the 5th of February of the present year. I was accompanied by Messrs. W. Beals and G. T. Quinby, volunteer aids. My first object was to review the conclusions I had come to, along with Dr. R. A. F. Penrose, jr., concerning the history of the South Carolina phosphates, which are set forth in the report on phosphate deposits in Bulletin No. 46 of the Survey, now in press. From the neighborhood of Charleston I went to St. Augustine, in order to obtain the materials secured in boring a well to the depth of 1,300 feet at that point. Through the kindness of Mr. Flagler, the owner, and of Mr. Kennish, the engineer of the Ponce de Leon Hotel, I had the good fortune to secure the material for the collections of the Survey.

From St. Augustine I proceeded to the lake district of Florida in order to determine the origin of the singular topography in that region. It appears probable that the sharp undulations of the sandy deposits in the lake district of Florida are due to the recent movement of marine currents over this part of the peninsula.

From the lake district I went by way of Tampa to Key West. From that island I made my way by sail-boat and on foot up the eastern coast of Florida to Titusville, near the head of Indian River, a distance of about 360 miles. From Key West to Virginia Key the route was devious in its course, as the object was to examine the interior and exterior portions of the Key district. From Virginia Key to Lake Worth the journey proved one of great difficulty, on account of the low stage of water during the dry season, which made it impossible to traverse the lagoons in a boat. After several efforts to cruise northward along the shore our boat was capsized in the night time at a considerable distance from shore and it was with some difficulty that our party recovered the land. From Lauderdale Government House of Refuge for Mariners to Lake Worth we were compelled to make our way on foot over the beach. From that point to Titusville the journey was made in the lagoons known as Jupiter River, St. Lucie Sound, and Indian River.

Approximate proofs of two distinct periods of elevation and subsidence which have affected the peninsula were obtained. It appears from my inquiries that the swamp region of the Everglades, including the greater part of Monroe and Dade Counties, owes its existence to the growth of the mangrove swamps, which bar the land waters from the sea, and in part to the existence of an old coral reef, now elevated to a height of about twenty feet above high tide, which forms a barrier extending from near Lake Worth to a point about thirty miles northeast of Cape Sable.

Traversing this reef from Cocoanut Grove Bay to the margin of the Everglades I found that, as determined by two Casella barometers with duplicate observations, in the time of lowest waters in the Everglades, the surface of the morass is sixteen feet above the sur-

face of high-tide mark, the distance between the two points being more than three miles. It thus appears probable that the drainage of this area may best be accomplished by canals cut through the reef.

It appears that the swamp districts of Florida, containing an area of not far from 25,000 square miles, are generally of a drainable nature and that they will yield land valuable for agriculture.

Since the opening of the field season of 1888 with the help of my temporary field assistant, Mr. George E. Ladd, I have begun work on the great section of stratified though highly metamorphosed rocks lying to the west and geologically below the Cambrian of Attleborough. Although this field presents great difficulties, we have so far succeeded in effecting a preliminary division of the beds into two series of schists and an intermediate division of limestones. The latter group of rocks are white crystalline deposits, having a total thickness of about a hundred feet, and closely resembling in their general nature, as well as in the nature of their surroundings, the limestones which occur in Bolton, Stowe, and Chelmsford, Mass., and at Rockland, Me.

Dr. Alfred Church Lane, by recent appointment an assistant in the Survey, has during the past year, under my direction, prepared a report on the geology of the peninsula of Nahant, Mass. This memoir will be transmitted to your office.

The following papers have been prepared for the press and communicated to your office, or with your permission given for publication to scientific journals:

A Report on the Geology of the Island of Cape Ann, Mass. (for the Ninth Annual Report of the Director).

On the Origin of the Divisions between the Layers of Stratified Rocks.

The Crenitic Hypothesis and Mountain Building.

On the Geology of the Cambrian District of Bristol County, Mass.

On the Occurrence of Fossils of Cretaceous Age on the Island of Martha's Vineyard, Mass.

My division is indebted to the authorities of the Old Colony Railway for valuable help in the prosecution of field work; to Messrs. George B. Leighton and John L. Gardner, jr., for photographic work on Cape Ann and elsewhere, the results of which have been embodied in my reports; to Messrs. William Beals and George T. Quinby for their efficient services as aids in my Florida work, in which journey they paid their own expenses; and to Messrs. T. W. Harris, George E. Ladd, and F. B. Lund for assistance in the Narragansett field.

Very respectfully, your obedient servant,

N. S. SHALER,
*Geologist in Charge.*

Hon. J. W. POWELL,
*Director U. S. Geological Survey, Washington, D. C.*

## REPORT OF PROF. RAPHAEL PUMPELLY.

DIVISION OF ARCHEAN GEOLOGY,
*Dublin, N. H., July* 1, 1888.

SIR: I have the honor to submit the following report upon the distribution of my work during the past year:

The work of my division has necessarily been concentrated upon the geology of western New England. The Green Mountains contain not only the key to the geology of New England, but, in the unraveling of their structure, also the settlement of other much disputed points, especially in regard to metamorphism. It is for these reasons that I have continued to concentrate our efforts upon the study of these mountains, feeling fully assured that the essential key lies in their structure, and that without it the geology of New England can not be known.

The important question of the conformable continuity or non-continuity of the Green Mountain series from top to bottom is not yet definitely settled.

Our contact observations give corroborative proof of the conformity of the quartzite with the overlying Stockbridge limestone, and Mr. Walcott has shown, from the fossils discovered by him in the quartzite, that this is of Middle Cambrian age. A considerable part of the rocks forming the Green Mountains proper lie below the top of this quartzite, in a series of quartzites, conglomerates, gneisses, and mica-schists, which undergo frequent transitions from one into another. In the process of mountain building these have been so compressed by lateral thrust, and often so contorted, that the evidence furnished at contacts, as to conformity, is not yet conclusive; and yet the importance of the question is such, that I shall continue to devote much attention to it.

Following my plan of working out the structure of broad zones across the mountain ranges, we have finished a map of the northern half of Berkshire County, Mass., based upon an immense number of observations. The work on the Hoosac Mountain, or eastern part of this map, was during the past year carried out by Mr. J. E. Wolff, assisted by Mr. C. L. Whittle, and that on the Greylock, or western half, was done by Mr. T. N. Dale, except a small area by Mr. W. H. Hobbs. This study has given us a very full knowledge of the various components of the Green Mountain series from the top of the Taconic schists down, together with an extensive insight into their lithology and phenomena of transition. It has also furnished a great amount of material illustrative of the structure of these mountains, and of mountain building in general.

East and south of this belt Professor Emerson has continued his

study of the strata flanking the Green Mountains on the east, and connecting his former work with the belt across the mountains.

Preparatory for the geologic work of the coming season Mr. H. L. Smyth has executed, in more or less detail, topographic surveys in southern Vermont and in southern New Hampshire, and since the latter part of May of this year he has been surveying a belt across the mountains between Wallingford and Plymouth, Vt. Among the surveys carried out by Mr. Smyth during the year, that of the Mount Monadnock and surrounding country forms a valuable topographic map, as well as a basis for geologic work.

A valuable collection of the fossil plants of the Rhode Island coal field has been made for the Survey by the Rev. E. F. Clark.

The study of the Triassic eruptive rocks of the Connecticut Valley has been continued by Mr. W. M. Davis.

I have the honor to be, sir, your obedient servant,

RAPHAEL PUMPELLY,
*Geologist in Charge.*

Hon. J. W. POWELL,
*Director U. S. Geological Survey, Washington, D. C.*

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## REPORT OF MR. G. K. GILBERT.

APPALACHIAN DIVISION OF GEOLOGY,
*Washington, D. C., July* 1, 1888.

SIR: I have the honor to submit the following report of work in my division during the fiscal year ending yesterday:

### FIELD WORK IN 1887.

In previous reports it has been set forth that the first work undertaken in the Appalachian region was the careful measurement of a series of sections. The beginning of the fiscal year found three parties engaged in this work: Mr. I. C. Russell, assisted by Mr. C. W. Hayes, in Alabama; Mr. Bailey Willis, assisted by Mr. Arthur Keith, in Tennessee; and Mr. H. R. Geiger, on the line of the Potomac. Mr. Russell closed his work early in September, his field season being abridged by the illness of his entire party. He succeeded, however, in completing the work on the sections. Mr. Willis completed his section work, and also made two detailed studies of geologic structure, making local plane-table surveys on a large scale for that purpose. He left the field about the middle of October. Mr. Geiger completed his section work and returned to Washington in the middle of November, the greater part of his field season having been spent in a study of the valley limestones and of their relations to the sandstones of the mountains overlooking the great

valley from the east and west. Mr. N. H. Darton was occupied during August, September, and the first third of October in a reconnaissance on the headwaters of the Greenbrier, New, and James Rivers of Virginia and West Virginia, for the purpose of determining the most available lines for the measurement of sections.

My own field work was a continuation of the investigation, described in previous reports, of post-glacial changes of level in the northern and northeastern States. A few weeks were spent in southern, northern, and western New York, in northern Pennsylvania and Ohio, and on the Maine coast.

## OFFICE WORK.

My attention in Washington has been largely given to administrative details under your immediate direction, but I have also spent some time upon the long-deferred report on the history of Lake Bonneville, now nearly ready for the press. I have also studied the literature germane to the subject of the summer's field investigation.

My assistants, after returning from the field, constructed the surveyed sections and prepared reports upon their various subjects of study. These reports are intended primarily to serve as office records and as a foundation for future field work, but they will also form at some future time the principal basis for the discussion of the comparative stratigraphy of the Appalachian region from Maryland to Alabama. Mr. Russell also spent some time in the revision of essays described in my last report, and in the preparation, now well advanced, of an index to the literature to the Jura-Trias system. Mr. Willis began a series of experiments suggested by the structure phenomena of his district, and designed to reproduce those phenomena in miniature by the application of horizontal stresses to stratified masses of varied composition, subjected at the same time to the vertical pressure of a flexible load.

Mr. Darton, after preparing a report on his reconnaissance, resumed work on the Appalachian bibliography, which is now nearly complete and has already been extensively used by various members of the Survey. He also spent much time in the revision of a list of papers on American geology previously offered for publication.

Prof. I. C. White continued work on the comparative stratigraphy of the Coal Measures of West Virginia, Pennsylvania, and Ohio, and his essay is now nearly ready for publication.

## FIELD WORK IN 1888.

The detailed section work to which so much attention has been given in the Appalachian division during the past two years was intended to pave the way for the mapping of formations, by indicating in advance the nature of the problems which would arise, and by solving as many of them as possible. This summer the areal

work is directly undertaken, the atlas sheet being the unit of survey. In this district each atlas sheet is bounded by meridians and parallels one-half degree apart, so as to include one-quarter of a square degree of area. The size varies with the latitude, but is in general about 1,000 square miles. Mr. Geiger began work on the Harper's Ferry sheet about the middle of June. All work south of Virginia was placed in charge of Mr. Willis, and under his direction Mr. Hayes has begun the survey of the Rome sheet, and Mr. Keith that of the Greenville sheet. Mr. Willis gives his personal attention to the yet unsettled problem of the relation of the schistose rocks at the southeast to the Paleozoic strata of the Appalachian folds. These parties are now in the field, and other parties will be organized later in the season.

A comparison of the columnar sections already determined in Maryland, Tennessee, and Alabama shows that it will be possible to recognize but a small number of formation boundaries in all parts of the Appalachian region. Not only are the more southerly columns shorter than the northerly, but they include a much smaller number of distinguishable subdivisions. Recognizing at the outset the impossibility of using a single legend for all the atlas sheets of the district and the improbability that the legends of any two adjacent sheets will coincide in all respects, I have arranged that the determination of the distinctions to be mapped on each atlas sheet shall be determined chiefly from a consideration of the local phenomena. In addition to the geologic map, a soil map will be prepared of each area.

Mr. Russell leaves the Appalachian work for the present to undertake a general review of the Jura-Trias system and its literature, and in connection with this work went early in June to Colorado, where he has examined the Jura-Trias sections exposed at Colorado Springs and at Cañon City.

## ASSISTANTS.

Mr. Geiger has been assisted while in the field by his son, Mr. F. W. Geiger, and has been aided in office work by Mr. R. B. Cameron, detailed for that purpose from the Geographic Division. Mr. Willis was accompanied for a few weeks in July, 1887, by Mr. R. R. Gurley, who continued the collection of fossils in the Tennessee district. At the opening of the present field season Mr. A. E. Woodward was added to Mr. Hayes's party, and Mr. A. C. Lane to Mr. Keith's. Prof. W. L. Webb was employed by Professor White as draughtsman from December to March, inclusive. Messrs. Russell and Willis in 1887, and Messrs. Hayes and Keith in 1888, have each employed two camp hands during the period of field work.

I remain, with great respect, your obedient servant,

G. K. Gilbert,

*Geologist in Charge.*

Hon. J. W. Powell,

*Director U. S. Geological Survey, Washington, D. C.*

## REPORT OF MR. C. R. VAN HISE.

LAKE SUPERIOR DIVISION,
*Washington, D. C., July* 1, 1888.

SIR: I beg to submit the following report of the operations of the division of the Survey now under my charge for the year ending yesterday:

The division has suffered a great disaster in the death of its former head, Prof. Roland D. Irving. He was stricken with paralysis of his left side May 27, and his death followed three days later. Professor Irving was the first head of the division, and to his great ability and unflagging industry its success in the past has been chiefly due. The division for eleven months of the year was under his supervision, and the work of the remaining month was a continuation of that laid out by him; so that the following account of its operations represents work which he directed. This being the case, I quote a paragraph from Professor Irving's last annual report, showing the plan of work of the division, to accomplish which the operations during the year have been carried forward:

As shown in former annual reports, the work set for this division includes especially a study of the great formations which lie beneath the Potsdam or basal Cambrian sandstone of the Northwestern States. The final object of this study is the preparation of a series of sheets for the great geological map of the United States called for by the organic law of the Survey. In order, however, that each color on these sheets shall cover rocks which are in some sort homogeneous and chronologically equivalent, a necessary preliminary to the mapping has been the ascertaining of the true chronological succession or natural classification of the pre-Cambrian formations of the region. These formations had been so inadequately studied, that the various geologists who in former years had occupied themselves with them, having confined their researches to restricted and disconnected areas, had failed to reach any such general agreement or to accumulate such a mass of trustworthy material as would warrant the adoption by the Survey of any final classification that had previously been suggested. As indicated in my last annual report, however, in the several years that have elapsed since the beginning of our investigation in September, 1882, we have made such progress towards a final classification, that, while I have felt it necessary to continue the special studies throughout the year just closed, I have also thought it wise to devote part of the force to the completion of the geology for the final sheets. These sheets are bounded by parallels of latitude and longitude, and comprise each one-fourth of a square degree. As a topographical basis for them we have at present only the surveys of the U. S. Land Office, except near the shores of Lake Superior, where the exceedingly accurate maps of the U. S. Engineer Office are available. For special purposes further topographical mapping will be needed, but for the outlining of the grander geological phenomena, such as will be given on the general map referred to, it is not thought that additional work of this kind will be necessary. Moreover, if such further topographical work should be deemed necessary for the sake of uniformity in the elaboration of the sheets of the final map, it can be done as well after the geological mapping as before, our geological boundaries being located by measurements from section corners. In our preliminary studies we have gathered material sufficient to do much of the final

mapping; but since in the field work for these preliminary studies it has been designed to follow the most instructive routes and to study the most characteristic exposures, rather than to cover the whole territory, various insufficiently examined areas have been left. The general structure of these areas is pretty well known, but our knowledge of them is not sufficient to allow of mapping. It has been my plan then, while continuing our special studies, to proceed also with the detailed examination of these unfilled gaps, in such order that the geology of the several sheets for which the Lake Superior Division of the Survey is responsible shall be completed sheet by sheet.

## FIELD WORK.

The field work of the division has been done by Professor Irving, Dr. W. S. Bayley, W. N. Merriam, and myself.

Professor Irving went into the field July 13. His time was divided between the Marquette, Felch Mountain, and Penokee regions, in all of which areas he visited a number of the most important localities. During a part of this time he was in company with Professor Pumpelly, of the division of Appalachian Archean Geology, and during the remainder of the time I was with him. His aim was to visit as many points as possible which could throw light upon the relations of the iron-bearing series and the green crystalline schists, gneisses, and granites with which they are associated. His field work was, then, a continuation of the special study in which he has been engaged for some years. It had long seemed to Professor Irving that the key to the solution of the difficult problems of Lake Superior geology was the separability by a great unconformity of the green crystalline schists, which are so closely associated with the iron-bearing series, from the clastic and chemical sediments of the iron-bearing series. All the work of previous years had pointed in this direction, and so conclusive were the results of the season's field study, that he had felt warranted in announcing this more positively than ever before as the true relation between the two series of rocks. Heretofore these green crystalline schists have been classed with the iron-bearing series by most writers.

The work laid out for me by Professor Irving was to do additional field work necessary to satisfactorily complete our joint memoir upon the Penokee iron-bearing series. Since my last visit to this region exploration and exploitation had exposed the rocks at very numerous points where before they had been hidden by the drift. The gaps were often quite wide, and our mapping was correspondingly uncertain. Work was begun about the middle of June of the previous fiscal year, and continued with one interruption to August 18, during a portion of which time I had the advantage of the company of Professor Irving. So extensive had been the exploration along the iron-bearing member, that I was able with great accuracy to locate for many miles the contact between this belt and the fragmental quartzite by which it is underlain. In the eastern part of the region,

in T. 47 N., R. 44 W. and 43 W., Michigan, west of Gogebic Lake, great uncertainty as to the true relations of the rocks had existed, notwithstanding detailed field work. We are now able, however, with some confidence to map this difficult region.

Field work, begun by Dr. W. S. Bayley in the latter part of the previous fiscal year, was continued during July and August, with the assistance of two woodsmen and two packers. The party was thus able simultaneously to follow two separate lines. During this time the country in the vicinity of Silver Lake, Michigan, and that bounded by Silver Lake on the east, Keweenaw Bay on the west, Lake Superior on the north, and the Duluth, South Shore and Atlantic Railroad on the south, was covered in some detail. The time was devoted principally to mapping the Huronian areas existing in this region. During July and August about 650 miles of section lines were followed. At the beginning of September the party was cut down to Dr. Bayley, with one woodsman and one packer, and in the latter part of this month only one assistant was employed. Work was continued along the line and a short distance north of the Duluth, South Shore and Atlantic Railroad. Only a few specimens were here collected, as most of the time was spent in excursions intended to afford material to check the results obtained during the earlier portion of the season. On the 1st of October the party left the field, after having examined quite thoroughly all that portion of the upper peninsula of Michigan lying north of the Duluth, South Shore and Atlantic Railroad, and between Marquette on the east and L'Anse on the west. During the season over 1,200 miles of country were traversed and eight hundred and ten hand specimens of rocks were collected. The limits of two areas of fragmental rocks were traced and mapped, and the Archean schists lying between these were carefully examined.

Mr. W. N. Merriam left Madison for Duluth July 9. Here he was joined by G. A. Buckstaff, who acted as a volunteer field assistant. From Tower they went to Grand Marais, where two Indians and canoes were obtained. The party then went, via Vermilion Lake and Little Fork River, to Rainy River. It then followed Rainy River to the Lake of the Woods. The entire south and west shores of this lake were coasted to the northwest angle, and thence to Rat Portage. From the northwest angle to Rat Portage a particularly full suite of specimens was collected as typical of a region described by Dr. A. C. Lawson, of the Canadian geological survey. From Rat Portage the party went to Port Arthur, where it disbanded. Mr. Merriam then went to Metropolitan, Mich., to begin a systematic detailed study of the Felch Mountain region. For this purpose he organized a party, consisting, besides himself, of a woodsman and two packers, and on August 28 he began work, which continued until October 11, when he was called to the Madison office by Professor Irving. Mr.

Merriam collected about one hundred specimens in his trip in northeastern Minnesota, and about one hundred and seventy-five in the Felch Mountain country.

Prof. C. W. Hall did a small amount of field work in the month of October in Kennebec, Pine, Aikin, and Carlton Counties, Minn., in continuation of his studies upon the granites and crystalline schists of central and southwestern Minnesota.

OFFICE WORK.

Professor Irving, in the office, gave the greater part of his time, and I have given practically all of mine, to the preparation of a joint memoir upon the Penokee iron-bearing series. The series comprises four belts of rocks, which are separated from each other by a difference in the original sediments which composed them. At the base is a formation of chemical or organic sediments — a limestone and chert member. Above this lies a belt of fragmental sediments — a quartz-slate member. Upon this rest the non-fragmental sediments of the iron-bearing member, and above the last is a second belt of fragmental sediments of great thickness. The series as a whole is separated by unconformities from the Archean rocks below and the Keweenawan above. It is brought to an end upon the surface at the west by the overlapping Keweenawan eruptives in T. 44 N., R. 7 W., Wisconsin, and at the east by the eastern horizontal sandstone, which, extending southward across the path of the iron-bearing series in T. 47 N., R. 42 W., Michigan, just west of Gogebic Lake, covers alike unconformably the Keweenawan, Huronian, and Archean rocks. Our work has involved a continuation of the studies of the origin of the ferruginous schists and iron ores.[1] This investigation has completely confirmed the general conclusion, published two years ago by Professor Irving, that these rocks were originally impure iron carbonates, essentially similar to the iron carbonates of later geological periods. Also, we have been able to fill in many of the details in the processes of alteration. The origin of the curious concretionary and brecciated character of many of the rocks and the series of changes which concentrated the ore in certain places and left others barren have been for the most part satisfactorily worked out.

Professor Irving prepared a prefatory chapter to Dr. George H. Williams's bulletin upon the greenstone-schist areas of the Marquette and Menominee regions of Michigan. This chapter discusses at length the relations of the granites, greenstone-schists, and adjacent iron-bearing series. It again maintains that the last is newer than and rests unconformably upon the green schists.

[1] Origin of the Ferruginous Schists and Iron Ores of the Lake Superior Region, by R. D. Irving, Am. Jour. Sci., 3d series, vol. 32, 1886, p. 255.

During the year Dr. Williams was engaged in the preparation of the above bulletin. This bulletin embodies the results of parts of two seasons' field work, supplemented by detailed microscopic studies of the materials collected, and contains about 700 pages of manuscript, 16 colored plates, and 33 figures. The bulletin is a contribution to the subject of dynamic metamorphism of eruptive rocks. The Menominee area embraces two bands of massive greenstones and associated greenstone-schists, which are intersected by the Menominee River at several points. All of these points offer excellent exposures, and from a careful study of them, both in the field and with the microscope, the conclusion was reached that these schistose rocks were originally eruptive belts (probably diabase and gabbro), which have subsequently been greatly altered and rendered more or less completely schistose by pressure. Intercalated dikes of acid eruptive rocks (granites and quartz-porphyries), occurring just above the Big Quinnesec Fall, have developed a similar schistose structure. The greenstone-schist area of the Marquette area is much more complex in its composition. There occur in this greenstone belt, which extends westward from Lake Superior, (1) regularly banded greenstone-schist, consisting of alternating layers of lighter and darker color; (2) homogeneous greenstones, both massive and schistose; (3) intercalated dikes of very massive greenstone; (4) massive and somewhat schistose acid rocks. The first of these classes is regarded as greatly altered diabase-tuffs. The second class is considered as massive flows of diabase or some allied type of eruptive rock, which has been rendered more or less schistose in certain places by the action of pressure. The third class consists of later and but little altered basic intrusions. The fourth class of acid eruptive rocks, which are often accompanied by tuff deposits, have been much altered by both dynamic and metasomatic processes. The macro-structure, micro-structure, and mineralogical alterations of all the rock types have been worked out and illustrated in great detail.

Dr. W. S. Bayley's time for the first three months after the close of the field season was spent in miscellaneous duties in the office. The remainder of the year has been given to the preparation of a bulletin upon the rocks of Pigeon Point, Minnesota. In this connection Dr. Bayley has prepared two papers for publication, one of which has already appeared.

The small amount of time which Prof. C. W. Hall has been able to give to office work has been devoted to a study of the rocks of central and southwestern Minnesota. Mr. W. N. Merriam has been engaged in platting the work of the field season, in drawing maps for contemplated publications, and in taking a large number of microphotographs (in which work he has become expert) from which to select illustrations for the reports.

During the year but two papers have been published, namely, "Is

there a Huronian Group?" by Prof. R. D. Irving,[1] and "On some peculiarly spotted rocks from Pigeon Point, Minnesota," by Dr. W. S. Bayley.[2] The former of these is a condensed yet full argument for the separability by great unconformities of the Huronian series from the underlying Archean rocks and from the overlying Keweenawan and Cambrian rocks. At the present time a bulletin upon the Greenstone-Schist Areas of the Marquette and Menominee regions of Michigan, by Dr. George H. Williams, with an introductory chapter by Professor Irving, and a paper for the American Journal of Science upon the Granites of Pigeon Point and Irving's Augite-Syenite, by Dr. W. S. Bayley, are ready for the printer. It is due to Professor Irving that a list be given of works in preparation in the division: (1) Monograph upon the Penokee Iron-Bearing Series, by R. D. Irving and C. R. Van Hise. This work is far advanced, and it is hoped that it will be ready for the printer within a few months. (2) Paper upon the Ferruginous Schists of the Penokee and the Animike Series, by R. D. Irving and C. R. Van Hise. This paper would have been ready for the present annual had Professor Irving lived. (3) Bulletin upon the Rocks of Pigeon Point, by Dr. W. S. Bayley. Much has been done upon this report and it is well advanced, yet a good deal of work will be required to complete it. (4) Bulletin upon the Crystalline Rocks of central and southwestern Minnesota, by Prof. C. W. Hall.

All of which is most respectfully submitted.

C. R. Van Hise,
*Geologist in Charge.*

Hon. J. W. Powell,
*Director U. S. Geological Survey, Washington, D. C.*

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## REPORT OF PROF. T. C. CHAMBERLIN.

Glacial Division,
*Madison, Wis., July* 1, 1888.

Sir: I have the honor to submit herewith a report of the work of the Glacial Division during the year ending June 30, 1888.

By joint arrangement with the geological survey of Canada, Assistant Geologist Warren Upham continued his exploration of the basin of the extinct Lake Agassiz, in Manitoba, until July 26. The area examined embraces the prairie portion of the lake bottom in Manitoba, reaching north to Riding Mountain and the southern end of Lake Manitoba, and from the Red River on the east to Pembina Mountain, the Tiger Hills, and Brandon on the west. His exploration also included a part of the basin of the Pembina, Souris, and Assin-

[1] Am. Jour. Sci., 3d series, vol. 34, 1887, pp. 204, 249, 305.

[2] Ibid., vol. 35, 1886, p. 388.

iboine Rivers, which brought into the ancient lake extensive delta deposits. From July 26 to September 22 Mr. Upham was engaged in field work at different points in and adjacent to the basin of Lake Agassiz, in Minnesota and Dakota, noting the general topographic features and the various glacial, lacustrine, and fluvial deposits, especially the lower beaches of the lake. His attention was also given to the very numerous artesian wells which are obtained within the drift deposits in many portions of the Red River Valley at depths varying from fifty to two hundred feet or more. A short journey was also made into the region west of the extinct lake basin and adjoining Minnewaukon Lake, the south side of which is bordered by very prominent and typical terminal moraines, as indicated in the Third Annual Report of the Survey.[1] Mr. Upham was assisted in leveling by Mr. Robert H. Young.

Leaving the field in September, Mr. Upham was engaged during the remainder of the year in embodying his data in manuscript and maps. A considerable part of his time was devoted to the compilation and discussion of the elevations determined by the railway surveys of the region under examination, and the reduction of his levelings by these means to the sea level. It was found that the interconnected railway profiles and the levelings of the U. S. Lake Survey and of the Missouri and Mississippi Commissions gave determinations of the heights of this central portion of the continent so close in agreement, as to justify the belief that the elevations of the beaches of the ancient lake may be accepted as true within limits nowhere exceeding five feet. All these elevations have been tabulated for publication as a bulletin of the Survey, to be entitled "Altitudes between Lake Superior and the Rocky Mountains."

Mr. Frank Leverett, special field assistant, was engaged the greater part of July, 1887, in the preparation of a report upon the drift deposits of that portion of Illinois lying north of the Kankakee River and east of the Fox River, which he had examined during the two preceding months. In the latter part of July he resumed field work upon a belt lying between Lake Michigan and the Valparaiso moraine in northwestern Indiana and southwestern Michigan. His study was carried north to the mouth of the Kalamazoo River, and embraced chiefly the tracing of beach lines and feeble moraines. This work occupied him until the latter part of September, when he undertook the study of a belt stretching eastward across the territory of conflicting glacial movements through the Lake Michigan, Saginaw, and Erie-Huron Valleys. This was worked eastward to the east line of Ingram and Jackson Counties, Michigan, reconnoitering lines being thrown out to the northward. The chief endeavor was to determine the border lines of the Lake Michigan, Saginaw, and the Erie drift movements. This study occupied him until early in

[1] Page 400.

November, when a parallel belt, adjacent on the south, was taken up and prosecuted until the middle of December, when field work was discontinued. The winter and early spring months were spent by Mr. Leverett in the mapping of his data, the preparation of a general map to embrace all the investigations of the Glacial Division about the head of Lake Michigan, and in the preparation of manuscript. On June 4, 1888, field work was resumed essentially where suspended, and the work of careful delineation of the various phases of the drift lying between the Kankakee Valley and the Erie Basin in northern Indiana was in progress at the close of the year.

Mr. I. M. Buell, special assistant, continued at intervals—as his location upon the field permitted him to do advantageously—supplementary field observations upon the bowlder trains from the isolated quartzite outcrops in Dane and Jefferson Counties, Wis., upon which he had been previously employed, as heretofore reported. The larger portion of the time given to the survey was devoted to the delineation of the remarkable drift topography of the region and the study of the topographic relations of the phenomena under investigation. In the latter part of the season the topographic work was undertaken by Mr. John R. Renshaw, of the Geographic Division. The remainder of Mr. Buell's time was devoted to the preparation of matter for his report.

The work undertaken by Prof. J. E. Todd, assistant geologist, consisted essentially of a continuation of his examinations of the drift deposits of the Coteau du Plateau du Missouri, between latitudes 44° N. and 46° N. He started for the field on July 7, and, aided by Mr. L. B. Avery, gave his attention first to the outer moraine, the nature of his investigations being essentially those indicated in my previous administrative reports. His course embraced the following points: Highmore, the Great Bend of the Missouri, Blunt, Pierre, Fairbanks, Forest City, Appomattox, Gettysburgh, Faulkton, Pembroke, Bangor, Bowdle, Leola, and Ellendale, where, August 12, Mr. Avery left the work, to undertake other duties. After August 16 Mr. A. H. Robbins aided Professor Todd until the close of the season. His remaining route embraced the following points: McIntosh County, Edgerly, northwestern Lamont County, Napoleon, Dawson, Sterling, Williamsport, Hoskins, central McPherson County, La Grace, Bowdle, Ipswich, and Faulkton. Six dozen photographs were taken, representing characteristic phases of the moraines, osars, terraces of the Missouri River, and general topography. Such time as he was engaged upon the survey during the remainder of the year was spent in the preparation of a systematic report upon the drift of the region indicated.

Prof. L. C. Wooster devoted a short time in August to a supplementary study of the territory examined by him during the preceding year, lying between the Kankakee Valley and Lake Michigan,

in Indiana. Such time as he was in the employ of the Survey during the remainder of the year was devoted to the preparation of his report upon this region.

Prof. George H. Stone devoted a portion of his time during the year to the completion of his report upon the glacial gravels of Maine, the nature of which is set forth in my preceding administrative report. His manuscript is nearly completed.

My own work during the year consisted of little more than the direction of the preceding operations, a small amount of field visitation incident thereto, the revision of manuscript submitted for publication, and the reading of proof.

Messrs. Upham and Leverett have been employed continuously in the work of the Survey throughout the year; all others, myself included, have worked upon a per diem basis, in connection with other employment in the main educational. In all cases I think the service rendered had been large in proportion to the time charged to the Survey, and had the advantage of mature and deliberate thought.

Very respectfully, your obedient servant,

T. C. CHAMBERLIN,
*Geologist in Charge.*

Hon. J. W. POWELL,
*Director U. S. Geological Survey, Washington, D. C.*

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## REPORT OF PROF. S. F. EMMONS.

ROCKY MOUNTAIN DIVISION,
*Washington, D. C., July* 1, 1888.

SIR: I have the honor to submit the following report of progress in the Rocky Mountain Division under my charge for the fiscal year 1887-'88.

As the past year has been essentially one of retrenchment and reduction of force, no new piece of work has been undertaken, and, outside the areas of work already in progress, such observations only have been made as could be carried on at little expense, and in more or less direct connection with those areas.

In accordance with your instructions, the offices and laboratory at Denver were given up at the commencement of the calendar year, and the collections and material transferred from there to Washington, together with those of my assistants whose services were not entirely dispensed with. As these collections had been accumulating during the seven years that the Denver office has been in existence, and were consequently very numerous, aggregating nearly ten thousand specimens, the labor of re-arranging, packing, and unpacking them for the new disposition rendered necessary by this transfer in-

volved the expenditure of a very considerable amount of time by myself and assistants which might otherwise have been employed upon the various monographs in course of preparation.

## FIELD WORK.

The season for field work this year extended from July to October, the former limit being fixed by the time at which the appropriations became available, the latter by the fall of snow in the mountains to such an extent as to obscure the geology. The work was carried on in the area covered by the topographic map already prepared, which has the town of Crested Butte, in Gunnison County, Colo., for its center. My party consisted of Assistants Cross, Eakins, and Smith, with two campmen and a pack-train outfit, as the country is too rugged to be reached by wagons. Preliminary geological investigations had already been carried on in this area in former seasons, and several unconformities discovered which have an important bearing on the history of the Rocky Mountains, as outlined in my report for the year 1884-'85. During the year 1885-'86, for reasons already given, no field work had been carried on there. It was my intention during the season of 1886-'87 to accomplish the final outlining of the geologic formations and the solution of the many interesting problems involved, with special reference to their bearing upon the theory of the formation of ore-deposits.

When in the year 1882 I made a hasty reconnaissance through the region of the Elk Mountains, I selected this area of about seventeen by thirty miles for our work, for the reason that at that time, in addition to its great interest from a purely geological point of view, it promised in the near future to be the scene of the most important economic developments on the west slope of the mountains in Colorado. Already valuable beds of bituminous, coking, and anthracite coals had been opened, and were reached by branches from the Union Pacific and Denver and Rio Grande Railroads respectively. In the numerous mining districts included within this area extremely promising deposits of metallic minerals had been opened, and the geological indications were such as to justify the belief that many rich bodies of ore must be concentrated in these mountains; hence it was reasonable to expect that by the time our maps were completed, and the general geologic structure of the region preliminarily determined, a large number of deep mines would have been opened, thus affording the opportunities for under-ground work, which are so essential for obtaining new facts bearing upon the history and origin of ore-deposits.

The progress of commercial development is, however, dependent upon a combination of factors, all of which it is impossible to forecast, and the expectations indulged in have not been realized up to

this time. Owing to the building of the new Colorado Midland Railroad across the mountains and the pushing of an opposition line by the Denver and Rio Grande Company down the valleys tributary to the Upper Grand River, industrial development has followed the northern instead of the southern slopes of the Elk Mountains. In this region, about fifteen to twenty miles north of the area covered by our map, large and valuable coal beds have been opened, iron ores and fine building and ornamental stones have been discovered, and, above all, extremely rich silver deposits have been vigorously developed under the impetus given by the railroads. The ores in the neighborhood of Aspen rival those of Leadville in richness and in qualities which facilitate reduction.

For the rapid development of mining districts, such as characterizes our Western regions, a certain amount of excitement in the nature of what is called a "boom" is an essential factor. The opening of one rich mine in a district naturally attracts capital, and thus furnishes the means of developing others, for the discoverers of ore-deposits are, as a rule, poor men, who can not afford to open their mines without outside pecuniary aid. Consequently miners and prospectors flock at once to the scene of active operations, abandoning temporarily the as yet undeveloped mines they may be working upon, however promising may be the indications of ore already obtained.

Such has been the history to a great extent of the area which we were investigating. To my disappointment I found very few deep mines regularly working, in spite of the excellent promise of the region from a geological point of view, and, though developments were regularly carried on in the coal mines, the local consumption of their product was extremely limited. For this reason the actual economic investigations in the region, although they have enabled me to make some generalizations upon the structural relations of fissure veins, which will, I think, prove of practical value to the miner, have not been as fruitful as I had hoped.

On the other hand, the more purely scientific results of our work, which are to be distinguished from the practical one mentioned above not by an absence of practical bearing but in that this bearing is more remote and indirect, have been more abundant and far more important than we had anticipated; especially has this been the case in regard to the development of eruptive rocks, which is the special province of Mr. Cross. The only regret in this respect has been that the scale and accuracy of delineation of topographic forms presented by our map are not such in all parts of the area as to admit of the representation thereon of all the details of geologic structure observed. This is in part due to the fact that Mr. Karl, who made the original survey, was unavoidably called away before the field season was completed, and in part to the adoption, for a portion of the area,

of topography made by members of the Hayden Survey, which did not contemplate the amount of detail which we find necessary. Hence, although the whole area was examined, and our notes are such as to enable us to lay down the geological colors upon the whole map, I deem it advisable for the perfection of the work upon a scale of accuracy which its scientific and practical importance justifies, that another field season be devoted to this area; and I would suggest that a topographer be attached to the party, to amplify and correct the topography where the complexity of the geologic structure demands it.

During the season I made a personal visit to the neighboring mining district of Aspen, partly for the purpose of seeking a possible solution of certain geologic problems which could not be definitely determined in the area covered by our map, and partly for the purpose of studying the remarkably rich ore deposits of the region, in the hope that I might be able in a short visit to make such determination of the geologic structure of the region, and of the relations of the ore deposits to it, as would prove of practical value to those engaged in exploring and working them. For the latter purpose I found that, owing to the peculiar complication of the structure, no absolute results could be obtained without an accurate topographic map of an area about three or four miles in extent, and as this would involve the expenditure of money considerably beyond that contemplated in the allotment to this division, I confined my observations to a week's study of the few general facts, which could be determined without a map.

After the close of the field season I visited some of the gold mines in the Cretaceous shales near Breckenridge, and the Queen of the West mine near Kokomo, in the Ten-mile district; the latter mine, which has been largely opened since the completion of our field work in that district, presents a most instructive type of ore deposits to which my attention had been called during my work in the Gunnison region, and whose proper development is particularly dependent upon a correct understanding of its structural relations.

OFFICE WORK.

Besides the preliminary studies necessary for a proper record of field observations made during the year, all the members of the division have been engaged in the final preparation of the two forthcoming monographs.

Mr. Eldridge has been occupied during the entire year upon that of the Denver Basin, having spent no small portion of his time in necessary modifications of the topographic basis. Both this and that upon the Ten-mile and Silver Cliff mining districts are now in an advanced state of preparation. In each case, however, new problems, involving often a further study of certain points in the field,

constantly crop out as the work proceeds. As the final publication of these monographs is necessarily delayed both from this cause and from the press of other matter at the Government Printing Office, I have thought it wise to publish from time to time, in scientific periodicals, digests or preliminary notices of matters of general and immediate interest in advance of the final monographs. In pursuance of this policy and under your authorization I have myself published during the year the following articles: "On the Origin of Fissure-Veins"; "On Glaciers in the Rocky Mountains"; "Preliminary Notes on Aspen"; "Structural Relations of Ore-Deposits."

Mr. Cross has published a paper on the "Denver Beds"—a new Tertiary deposit occurring in the Denver Basin region; and Mr. Eldridge a preliminary sketch of the other formations occurring in that basin, of their stratigraphic relations and structural features, and of the deposits of coal occurring there.

The monograph upon the Geology and Mining Industry of Leadville was finally issued in September, 1887.

Very respectfully, your obedient servant,

S. F. EMMONS,
*Geologist in Charge.*

Hon. J. W. POWELL,
*Director U. S. Geological Survey, Washington, D. C.*

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## REPORT OF MR. ARNOLD HAGUE.

YELLOWSTONE NATIONAL PARK DIVISION,
*Washington, D. C., June* 30, 1888.

SIR: I have the honor to submit herewith the following report of operations conducted under my charge during the year ending June 30, 1889.

In accordance with your instructions to begin field work in the mountains adjoining the Yellowstone Park as early in the season as the retreating snows would permit, I authorized Mr. J. P. Iddings to leave Washington for Bozeman, Mont., to engage the necessary camp men and to outfit the party for the season of 1887. He established camp just outside the town of Bozeman June 17, and after the usual delay incident to such preparatory work he left for the Mammoth Hot Springs, where he made the first permanent camp for geological work. Detained by official duties in Washington, I did not reach the park until July 13, where I found most of the corps already assembled, Mr. Iddings, with a party, having been at work in the Gallatin Range, and Mr. Walter H. Weed busy with investigations connected with the outlying and less important hot spring areas. The organization of the party was in every way quite as satisfactory as in previous years, while the experience gained by the regular mem-

bers of the corps in this special field of research added greatly to the value and efficiency of the work. The scientific corps of assistants was made up as follows: In geology, Mr. J. P. Iddings and Mr. W. H. Weed, the regular members of the Yellowstone Park Division, and Mr. A. C. Gill, of Johns Hopkins University, who rendered efficient service as volunteer assistant throughout the field season; in topography, Mr. Anton Karl was in charge, engaged in making detailed surveys of the principal geyser basins and the Mammoth Hot Springs, and in this work was ably assisted by Mr. J. R. Bien and Mr. H. B. Williamson. Mr. E. H. Shuster performed the duties of secretary and disbursing clerk.

In order to facilitate the work and to meet the requirements of the topographic branch of the surveys main camps were established in the different geyser basins. The first headquarter camp was located at the Upper Geyser Basin, followed by others during the summer at the Lower Geyser Basin, the Norris Geyser Basin, and closing the season at the Mammoth Hot Springs. This arrangement also allowed ample time for the annual study of the principal hot spring and geyser areas. To these main camps the parties engaged in geological surveys in the mountains return for their supplies and for consultations over the problems presented in the advancement of the work.

Resuming geological work immediately to the eastward of the country surveyed the previous autumn, the greater part of August and September was spent near the headwaters of the Yellowstone and Snake Rivers, among the mountains of the northern end of the Wind River Range and the rough country connecting the latter range with the Absarokas. The latter part of the season was occupied in the examination of the mountains along the eastern side of the park among the snow fields and streams which supply Yellowstone Lake, the grandest single reservoir in the Rocky Mountains.

The surveys progressed steadily throughout the autumn without serious delays or obstacles until October 1, when, under instructions, all field parties returned to Mammoth Hot Springs, and from that time forward the work was confined to the immediate neighborhood of the springs or to the cañon of the Yellowstone. On October 17, topographical surveys having been completed, work in the park was abandoned, and the party finally disbanded at Bozeman, Mont., October 25. Early in November all the regular assistants reported for duty in Washington and immediately began the investigation of the rich collection of geological material gathered during the summer. For the greater part of the season the parties were engaged in the mountains which pour their waters into Yellowstone Lake. In comparison with its size the drainage area of the lake is small. This is readily accounted for by its great altitude above sea level and the very favorable conditions of the surrounding country for receiving a heavy snow-fall throughout eight months of the year. Over a

great part of this area these snows are protected by the forests from the dry westerly winds, and the water is allowed to percolate the soil gradually, supplying the springs and streams which feed the lake. The timber everywhere comes down to the water's edge. The altitude of Yellowstone Lake is 7,740 feet above sea level, with a surface area of 139 square miles and an indented shore-line of nearly 100 miles. As yet we possess but little accurate knowledge of its depth, although there is no question that it presents the grandest natural store-house for water within what is known as the arid region of the West. If the broad valley of the Yellowstone for 200 miles is ever to be settled with a prosperous people, this body of water will be of inestimable value for the purposes of irrigation. From careful measurements made of the flow of the Yellowstone River just below the outlet of the lake the discharge of water was found to be 1,525 cubic feet per second, or about 34,000,000 imperial gallons per hour. The gauging of the stream took place in September, when the lake stood at a lower level than at any other period of the year. But few large streams flow directly into the lake, the Upper Yellowstone receiving by far the greater part of the waters from the mountains before it discharges into the lake.

Previous to this season the source of the Upper Yellowstone, so far as I am aware, had never been explored. Reports that one or two hunters previously followed up the river have reached me from time to time, but they left no record of their trip behind, and I saw no evidence of man near the source of the stream. The river rises in an immense snow field on the north side of an isolated peak, about twenty-five miles south of the southern boundary of the Park. The peak attains an elevation of over 12,250 feet above sea level, and has been long recognized as a prominent point by all topographical survey parties. Although never visited, it has been designated as Yount's Peak, after a trapper who lived for a long time along the banks of the Yellowstone. Three rivers—the Yellowstone, Gray Bull, and Buffalo Fork of Snake River—find their sources upon the abrupt slopes of this peak. To the southward and not far distant rises the Wind River. The region is an uncommonly rough one, with profound gorges penetrating far into the mountains and separated from each other by mere knife-edges of rock. The entire country is made up of volcanic material, for the most part andesitic breccia.

On May 1 the Excelsior Geyser, in the Midway Basin, was discovered in action, but as the telephone wires were out of order, no report of the eruption reached the Mammoth Hot Springs until several days later. Captain Harris, acting superintendent of the Park, visited the basin on May 9, and since that time the geyser has been seen almost daily, with no indication, so far as reported, of any falling off in the intensity of the eruptions. In the autumn of 1882 the

Excelsior Geyser was frequently seen playing with great violence, but since that time no eruptions have been witnessed, and all evidence of action within the interval is wanting. If the information furnished me is correct, the Excelsior is the most powerful geyser in the park to-day, as it was in 1882. The eruptions took place at intervals of about one hour, varying from fifty-five to seventy minutes. The column of water is estimated to be 16 feet in diameter at the base and to be thrown out to a height of 150 feet into the air. During the early eruptions rocks were hurled violently from the crater, frequently falling one or two hundred feet from the vent. Captain Harris has kindly forwarded me specimens of these ejected materials, which consist not only of siliceous sinter, but pieces of volcanic lava, probably from the underlying rock. That the Excelsior should have remained dormant for six years after the grand display of 1882 and then have burst forth again with renewed activity and energy is certainly very remarkable. The cause is not readily seen. With our previous knowledge of the country an investigation of the ground may throw some additional light upon the subject of thermal activity in this region. I anticipate that a study of the changes produced by this sudden outbreak will at least furnish some valuable data bearing upon the geological questions involved.

During the winter and spring the force in the office has been constantly engaged upon the results obtained in the field, writing out in permanent form the field notes and at the same time carrying on a number of investigations upon various subjects connected with the problems presented in the Park. In addition to this work much time has been devoted to the general question of the origin and classification of the crystalline rocks and their mode of occurrence. This is an investigation presenting fresh problems from year to year, but which promises at no distant day to furnish important results. In this work we have had much valuable aid from the Chemical Division of the Survey, which has furnished us with a large number of chemical analyses of volcanic rocks.

Since his return to the office Mr. Anton Karl has prepared seven maps, the result of his last season's field work, as follows:

No. 1. Firehole River, Upper Geyser Basin; scale, 1 inch to 200 feet; contour interval 5 feet.

No. 2. Upper Geyser Basin; scale, 1 inch to 500 feet; contour interval 20 feet.

No. 3. Midway Basin; scale, 1 inch to 100 feet; contour interval 5 feet.

No. 4. Lower Geyser Basin; scale, 1 inch to 600 feet; contour interval 10 feet.

No. 5. Norris Geyser Basin; scale, 1 inch to 300 feet; contour interval 10 feet.

No. 6. Mammoth Hot Springs and Terraces; scale, 1 inch to 200 feet; contour interval 5 feet.

No. 7. Mammoth Hot Springs Basin; scale, 1 inch to 800 feet; contour interval 20 feet.

On these maps Mr. Karl has located all the geysers and hot springs within the area surveyed and delineated the physical features of the

country in a manner to meet all the requirements of science and the needs of tourists who every year visit the Park. The maps are fine examples of topographical work, highly creditable to Mr. Karl and the Geological Survey.

With your approval, I published in the American Journal of Science, September, 1887, a short paper entitled, "Notes on the Deposition of Scorodite from Arsenical Waters in the Yellowstone National Park." Scorodite, a hydrous arseniate of iron, occurs both crystalline and amorphous in widely separated localities, but so far as I am aware this deposition from thermal waters has never been noticed. Nearly all the hot waters of the geyser basins carry arsenic, but only in a few instances do the conditions seem favorable for the deposition and preservation of scorodite. It is found at Joseph's Coat Springs, on the east side of the Yellowstone Cañon, and also at the Constant Geyser, in the Norris Geyser Basin, where it occurs as a deep-green amorphous mineral. Scorodite is decomposed readily into limonite, which in turn disintegrates and is mechanically carried away by running water. The value of this water for medicinal purposes can only be determined after long experience under proper medical guidance. Arsenical waters of sufficient strength to be of value in medicine are of rare occurrence and unknown to America. The experience of thousands of invalids at the famous sanitarium of La Bourboule, in the volcanic district of the Auvergne, attests the remedial properties of arsenical waters. The chemical investigation of the thermal waters of the Yellowstone National Park undertaken by the Geological Survey may prove them to possess valuable curative properties.

In addition to his other duties, Mr. Iddings, during the winter, devoted considerable time to a study of a collection of volcanic rocks brought in from northwestern New Mexico in the autumn of 1887 by the Director of the Geological Survey and Mr. W. H. Holmes. The rocks presented so many features of special interest to students of volcanic lavas, that Mr. Iddings prepared a short paper, to be published as a bulletin of the Geological Survey, giving the principal results of his investigations. The paper is entitled, "A Group of Volcanic Rocks from the Tewan Mountains, New Mexico, and on the Occurrence of Primary Quartz in Basalt." The rocks consisted chiefly of rhyolite, rhyolitic tufa, and ash, with some andesites and basalts. The rhyolites are characterized for the most part by abundant porphyritic crystals of quartz and sanidine. The andesites range from mica-andesite through hornblende-mica and hornblende-pyroxene-andesites to pyroxene-andesites, the most basic variety being hypersthene-andesite. The basalts present several varieties; those from Rio Grande Cañon are remarkable for the abundance of rounded grains of quartz. The whole group of rocks forms a characteristic series from rhyolite to basalt, whose mineral composition varies from

one extreme to the other. The second part of the bulletin describes several other occurrences of quartz-bearing basalt, among them one from Santa Maria Basin, Arizona, collected by Clarence King, and another from Elk Creek, Colorado. The paper discusses the possible physical features which may have attended the crystallization of the quartz in such a basic magma, and shows that quartz-bearing basalts in some instances have the same chemical composition as basalts without quartz. Mr. Iddings reaches the conclusion that such quartz grains are to be attributed to certain physical conditions attending the early existence of the molten magma rather than to the chemical composition. He suggests that the crystallization of quartz from a basaltic magma may be due to the influence of absorbed water vapor under great pressure, as has been shown to be the case in the occurrence of fayalite in rhyolitic obsidian.

Mr. W. H. Weed has devoted considerable time to the preparation of a paper upon the algeous growths found in the hot springs and pools throughout the Yellowstone National Park. The influence of these low forms of vegetable life in secreting the silica contained in these waters can hardly be overestimated, and is certainly far greater than one would at first be led to suppose. Mr. Weed gathered a large amount of material bearing upon this subject, and his knowledge of geology, botany, chemistry, and microscopy were all brought to his aid in the investigation. As the article is to appear as an accompanying paper to the Ninth Annual Report of the Director, a more extended notice in this place seems unnecessary.

Very respectfully, your obedient servant,

ARNOLD HAGUE,
*Geologist in Charge.*

Hon. J. W. POWELL,
*Director U. S. Geological Survey, Washington, D. C.*

## REPORT OF CAPTAIN C. E. DUTTON.

DIVISION OF VOLCANIC GEOLOGY,
*Washington, June* 30, 1888.

SIR: I have the honor to submit the following report of the work done in the division under my charge during the fiscal year of 1887–88:

In the field Mr. J. S. Diller completed the geological survey of the district tributary to Lassen Peak, and also the district which embraces the northern part of the Sacramento Valley in California. His report, which has already been forwarded for publication, adds much to our knowledge of the geology of those tracts and clears up many important questions. His lithological work is of special value, as it brings to light some new and important facts respecting the constitution and genesis of the volcanic rocks of this region.

The project for work in the Cascade region has been extended in its scope. Originally it was intended to carry the survey from the fortieth parallel northward to the forty-ninth in such manner as to include only the strip of country embraced between the one hundred and twenty-first and one hundred and twenty-third meridians, and the topographic survey had been planned and begun in conformity with this project. The progress of the geological investigation, a portion of which followed the topographic work, while another portion in the nature of thorough reconnaissance preceded it, developed clearly the fact that such limits were arbitrary and illogical. The proposed lines would cut off large and important portions of a geological province essential to its proper understanding. The Cascade Range and all the country to the west of it constitute both a geologic and a geographic unit, which can not properly be thus dissociated.

The Coast Range, from the fortieth parallel to Puget Sound, is a region which seems at first to be dissociated from and strongly contrasted with the Cascade Range; and indeed the contrast is in some important respects magnified rather than diminished by further investigation. But, on the other hand, it has been found that there is a dependence between the two ranges so close and inseparable, that they may be regarded as one region, having a common and interdependent history. The evolution of the one is a half phase of the evolution of the other. The study of both must eventually throw great light upon the geologic history of the western portion of the continent. It has therefore been deemed best to extend the field of inquiry so as to include all of the country between the Great Basin region and the Pacific Ocean and north of the fortieth parallel, irrespective of particular meridians. The whole forms a single geological province, with a history of its own. Nor are its lithologic and mineralogic features less distinctive.

The detailed geological work in this field during the past season has been limited to that accomplished by Mr. Diller, as already mentioned. Previous reconnaissances are already sufficiently in advance of the topographic work, which has proceeded rather slowly. The extreme ruggedness of the country, the comparative shortness of the field season, and the smoke which fills the air and seriously obstructs topographic work are the reasons why the advance of the latter is relatively slow. During the past season, however, considerable progress was made in the topographic survey of the southwestern corner of Oregon, and another season will probably yield the maps which will be necessary for entering the Coast Range in northern California and southern Oregon.

My own labors were not in the field during the past year. The completion of the investigation of the Charleston earthquake fully occupied my time, and the work proved to be much more protracted

and difficult than was anticipated. The monograph, however, has been completed and is this day forwarded and submitted, with a view to its publication in the present volume.

Very respectfully,

C. E. Dutton,
*Captain of Ordnance.*

Hon. J. W. Powell,
*Director U. S. Geological Survey, Washington, D. C.*

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## REPORT OF MR. J. S. DILLER.

Division of Petrography,
*Washington, D. C., July* 1, 1888.

Sir: Herewith I have the honor to submit a report of work done in the Petrographic Laboratory, under my supervision, for the fiscal year ending June 30, 1888:

Many specimens of rocks and minerals have been submitted to the laboratory for determination, with queries in many cases as to their importance and value for particular purposes. The determination of such specimens is sometimes a matter of considerable interest, and yields results of scientific as well as economic value.

In a furnace slag from western Pennsylvania was found an abundance of Gehlenite—a silicate of alumina, iron, and lime—which has not been previously reported as occurring in this country. It is of interest chiefly to those who are studying or teaching petrography, and desire to obtain a good example of a quadratic mineral to illustrate the optical properties of that system.

The presence of chalk in this country has been a matter of doubt for many years. Mr. R. T. Hill has recently described formations in Texas which in their chemical composition, physical features, and geological history he maintains are essentially chalk. A microscopical examination reveals the fact that, like similar formations in Europe, they are made up of the remains of foraminiferal organisms, and are true chalk.

In cooperation with Prof. F. W. Clarke, who was studying chemically the genesis of the nickel ore genthite, a microscopical examination was made of the ore and of the rock with which it is associated at Riddles, Oregon, as well as in North Carolina and New Caledonia. The result fully confirmed Prof. Clarke's view, that the ore was produced by the alteration of nickeliferous olivine in the adjacent peridotite. Of all eruptive rocks peridotite is the richest in precious gems, and it is found occasionally containing valuable ores and metals. It is well known in many cases to be the home of the diamond, precious garnets, pyroxenes, peridotes, and platinum, and upon its borders have been found valuable deposits of corundum and its

gems, as well as masses of iron ore and chromite, and to this list may also be added genthite. The results of the investigation have been published.[1]

One of the most remarkably pleochroic minerals known has recently been found at Harlem, N. Y., and identified as dumortierite, a mineral which has hitherto been found only near Lyons, France. Among a lot of specimens recently sent from Arizona to Prof. F. W. Clarke, for identification, the same mineral has been discovered. On account of its petrographic importance the results of its study will soon be published.

Silica is by far the most abundant of all rock constituents. It has been estimated to form half of the earth's crust. In a great majority of eruptive rocks it forms a much larger proportion, rising even as high as eighty per cent. of the mass. It is of special economic interest in being the most important gangue of precious metals and their ores. In the Far West, when a prospector is searching for gold in its native haunts he looks for quartz. Any line of investigation which promises to contribute to our knowledge of the origin and genesis of quartz may therefore be regarded as worthy of particular attention.

The latest lava erupted in the vicinity of Lassen Peak is basalt, rich in quartz, and the consideration of it has opened up the question of the origin of porphyritic quartz in all lavas as well as in plutonic rocks. A survey of the whole field furnishes strong evidence in favor of the view that *porphyritic quartz is one of the first minerals to crystallize in the eruptive rock in which it is contained.* It appears to have originated under conditions of extreme pressure, which perhaps would not allow complex molecules like those of the iron-magnesian silicates to form. This view is at variance with the generally accepted opinion of Rosenbusch, and the point at issue is of great importance in considering the relations between the mineralization of a magma and its volcanic activity.

Within the last few months the material already collected for the educational series of rocks has been brought together and it is being trimmed for distribution. When the two hundred collections contemplated in the original plan are completed, each one will contain one hundred and twenty-eight specimens. Of this number there will be sixteen to illustrate the condition, structural features, and decay of rocks; there will be forty-seven non-crystalline stratified rocks; twenty-three crystalline stratified rocks; and forty-two massive or eruptive rocks. Nine thousand eight hundred specimens have already been collected, and arrangements have been made to collect over fifteen thousand during the approaching field season. Most of these will be gathered by geological field parties without greatly increasing their expenses. The preparation of the material for dis-

[1] Am. Jour. Sci., 3d series, vol. 35, 1888, p. 484.

tribution after it has been collected will be delayed somewhat awaiting the publication of reports in which the specimens are described. The numerous applications already received for the series clearly indicate the need of it, and it is believed the series will be a useful aid in the cause of popular education.

Mr. Hermann Ohm has been engaged continuously in the preparation of thin sections and polishing specimens for study. During nine months he was assisted by Frederick C. Ohm and W. S. Hunnell, who were for three months detailed to other divisions of the Survey. Three thousand four hundred and six thin sections of ordinary size and fifty-one of extra large size have been prepared during the year. Seventy-two specimens were ground and polished.

During the last two months Mr. W. B. Smith has been engaged in trimming specimens for the educational series of rocks.

I have the honor to be, very respectfully, your obedient servant,

J. S. Diller,
*Geologist in Charge.*

Hon. J. W. Powell,
*Director U. S. Geological Survey, Washington, D. C.*

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## REPORT OF MR. GEORGE F. BECKER.

California Division,
*Washington, D. C., July* 1, 1888.

Sir: At the beginning of the last fiscal year my report on the Geology of the Quicksilver Deposits of the Pacific Slope was almost complete, and I transmitted to you a summary of the work, which appeared in your Eighth Annual Report. The manuscript was actually transmitted on July 19. A few days subsequently I made a somewhat important discovery connected with the subject. It is that, while ammonium carbonate completely precipitates cinnabar from natural solutions at ordinary temperatures, the presence of this substance at temperatures above the boiling point and at corresponding pressures is compatible with the solution of large quantities of cinnabar. This discovery explains the fact that while at Sulphur Bank there is much evidence that the deposition of cinnabar is still in progress, no trace of mercury can be detected in the waters of the hot springs; for these are ammoniacal. When the Sulphur Bank was first exploited no cinnabar appeared at the surface, and the ore was not discovered until considerable excavations had been made. This fact had always seemed to me very strange, but it is now explained by the behavior of ammonia. The sulphide was all precipitated before the water could reach the surface. The Sulphur Bank thus affords a very remarkable instance of the precipitation of ores by relief of pressure and diminution of temperature; one in which a natural

process assumes the form of a "quantitative separation." Its elucidation renders our knowledge of the methods in which cinnabar and the minerals associated with it are dissolved and precipitated fairly satisfactory.

During the year I have made a very careful microscopic study of the ores and rocks of Almaden, for the sake of comparing its geology with that of the deposits of the Pacific slope. All the observers who have published geological descriptions of this mine have reached or adopted the conclusion that cinnabar has been deposited by substitution for the more or less indurated quartz sandstone forming the country rock. No such substitution occurred in California, and it was one of the main purposes of my visit to Spain to study this phenomenon. My observations in the mine and microscopical studies of the ore show that the hypothesis of substitution is erroneous. The cinnabar at Almaden, like that of California, has been deposited exclusively in pre-existing openings, and it is everywhere accompanied by gangue-quartz, which has crystallized from the same solutions at the same time, excepting in the rare cases in which heavy spar plays the part of gangue mineral.

The Almaden mine, in my opinion, is opened on three true simple fissure veins, nearly but not accurately coinciding with the stratification of the country. The vein matter consists of fragments of wall rock more or less impregnated with ore, which also occupies the cracks between the fragments. The cinnabar is everywhere accompanied by pyrite and by quartz or barite. Dikes of diabase occur in the mine. They are much decomposed, and contain cinnabar in cracks and vesicular cavities. The ore deposition was therefore subsequent to the eruption of diabase, and it was probably a consequence of the eruption. The famous "piedra frailesca" is not, in my opinion, eruptive but, as De Prado considered it, a breccia of sedimentary rocks.

In October last I was requested to contribute to Mr. Edward Atkinson's report on Bimetallism in Europe an opinion as to the future yield of the precious metal mines and the probable relative prices of gold and silver.

A portion of my attention during the past year has also been devoted to subjects to which I hope to call your attention on a future occasion, but which are not yet sufficiently advanced to be reported upon.

The preliminary survey of the Gold Belt, the character of which is described in my last report, has been advancing steadily during the past year, and will continue to progress as fast as the topographical maps are furnished me. Many facts of great interest have been discovered, but it is not my purpose to elaborate special features of the geology of the region until, the preliminary survey and map being complete, I am fully acquainted with the opportunities pre-

sented for the study of the principal questions involved. One important addition to our means of arriving at conclusions concerning the metamorphic rocks of the Belt has recently been made by Mr. H. W. Turner, who has found *Aucella* in Tuolumne County, in which this important fossil had not hitherto been detected.

During the year Messrs. Melville and Lindgren have transmitted the manuscript of a bulletin, "Contributions to the Mineralogy of the Pacific Coast," recording a number of novel observations made on the collections for the geology of the quicksilver deposits. Messrs. Melville and Turner have also completed a bulletin on the geology of Monte Diablo. The field work and geological map are by Mr. Turner, while Dr. Melville has made a chemical investigation of the metamorphism; a very important study. Much work has been done for Monograph XIII and for this bulletin on the subject of metamorphism; but these are only beginnings. We already know of processes of metamorphism in the Sierra, which, though analogous to that studied in the Coast Ranges, present great peculiarities; and I have no intention of relaxing my efforts to contribute to this subject until the geology of the Gold Belt is completed as far as I am able to carry it.

Very respectfully, your obedient servant,

G. F. Becker,
*Geologist in Charge.*

Hon. J. W. Powell,
*Director U. S. Geological Survey, Washington, D. C.*

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## REPORT OF MR. W J McGEE.

Potomac Division of Geology,
*Washington, D. C., July 1, 1888.*

Sir: I have the honor to submit the following report of operations in the Potomac Division of Geology during the fiscal year ending June 30, 1888:

### FIELD WORK.

*Researches in the Middle Atlantic Slope.*—As during preceding years, frequent opportunities were found in the intervals of office work for noting the exposures afforded by natural and artificial excavations in the District of Columbia and vicinity, and somewhat voluminous notes, together with sketches and photographs of interesting exposures, were made and preserved. The geologic phenomena of the District are obscure and puzzling; their significance could be interpreted only after the development of special methods of research and new criteria of discrimination and classification. Nevertheless they are typical for a considerable part of the middle Atlantic

slope, of which the history has not yet been read in detail. So unusual caution was required at every step, and the investigation has necessarily been slow. It is believed, however, that the requisite methods and criteria have now been developed, and that by far the larger part of the data required for monographing the region in a satisfactory manner have been accumulated.

The formations and the topographic provinces represented in the District extend southward and northward for long distances, and different journeys, already reported, have been taken in both directions, with the object of gaining clearer insight into the history recorded alike in the formations and in the configuration of hills and valleys. Another such journey was made during the closing days of July and the early part of August last. It covered the ground in the vicinity of the fall line between Washington and New York, and was made on horseback. Since I had the pleasure of your company during half the trip, it will suffice to say merely that many new data were collected concerning (1) the Potomac and Columbia formations, (2) the great displacement of the middle Atlantic slope, (3) the history of river development of the region, and (4) the origin and relations of the relic-bearing Trenton gravels.

A synopsis of results of the investigations of the last five years in the middle Atlantic slope appeared in the American Journal of Science for February, April, May and June of this year.

In the researches in this region, attention has been given chiefly to the clastic and generally unconsolidated deposits of Mesozoic and Cenozoic age and to the correlative phenomena of erosion, but attention has been incidentally given throughout to the crystalline rocks of the Piedmont belt; and during the latter portion of the year Dr. George H. Williams, of the Johns Hopkins University, Baltimore, in his intervals of leisure, has been employed under my general direction in investigating the structural relations of these rocks about Baltimore and along the Susquehanna River. The results of some portions of Dr. Williams's admirable researches have come to your knowledge directly and have been made public from time to time by your permission, and the work requires no further mention here.

*Researches in Missouri.*—In accordance with your instructions I visited Macon County, Mo., toward the end of September last, and made a study of the local geologic phenomena and their bearing upon questions relating to artesian water supply, natural gas, coal, etc., in northern and central Missouri. The tract selected for special study is the southern central quarter of Macon County. Its geologic structure is simple, but representative of that of a considerable part of the State. Within it occur considerable coal fields, one of which—the Bevier field—is regarded as among the best in the trans-Mississippi coal basin; and since it has been neglected by geologists since 1855, it afforded a practically new field for investigation,

as well as one in whose resources the citizens of the State were especially interested. The investigation was made in such manner as seemed best to meet the requirements of the citizens of northern Missouri, and its results were communicated to the public orally as well as through the press of Macon. A more formal report was subsequently prepared, and in order that it might promptly reach the people of the State, it was conveyed to the Academy of Science of St. Louis for publication. It has already appeared as one of the memoirs in volume V of the Transactions of that society, as well as in separate form.

*Researches in Kansas.*—The surveys of areal geology and the investigations of natural gas, petroleum, salt, etc., commenced during a previous year in southeastern Kansas, by Mr. Robert Hay, were discontinued during most of the year by reason of the limited funds for such work at my disposal. Mr. Hay has, however, continued his activity in geologic work, and, with your permission, I have authorized him to publish certain papers on the resources of Kansas, embodying information collected while he was in the employ of the Survey, in the Transactions of the Kansas Academy of Science and in the report of the Kansas State Agricultural Society.

In accordance with your instructions I visited Fort Riley (near Junction City), Kansas, in January last, for the purpose of conferring with Capt. George A. Pond, assistant quartermaster, U.S. Army, concerning a detailed geologic survey of the military reservation at that point. This is one of the most extensive military reservations in the country. It is located in the exact geographic center of the United States and upon important transportation lines, and the different portions of the country are readily accessible from it, and, in the judgment of the officers stationed there, is destined to become at no distant day one of the most important military stations in the the country. A considerable enlargement of the station, including the construction of armories, ordinance store-houses, new quarters for officers and men, stables, etc., has recently been projected and the questions of the possibility of artesian water supply, of the proximity of building stones and brick clays, of the existence of coal seams, of the probability of the existence of natural gas, of the accessibility of natural deposits of salt, of the best system of sewerage under the geologic conditions there obtaining, etc., have become important. The area of the reservation is about thirty square miles; but it will be necessary to carry the geologic survey over a considerably larger area in order to meet the requirements of the station. During my stay in Kansas I made a hurried reconnaissance, with the object of ascertaining the desirability and possibility of the the survey asked for by Captain Pond, and at the same time preparing plans for the execution of the survey during another fiscal year.

*Researches in Indiana.*—Last year witnessed a great extension of the known area of natural gas westward in Ohio and Indiana; and during the greater portion of the year exploitation of the gas field was carried forward energetically by capitalists in both States. The test bores of the prospector when properly utilized are of great value to the geologist; for not only is the area of the gas field determined and its boundaries defined, but the stratigraphic succession may be ascertained as well by their aid. The last of these uses becomes exceedingly important in a region which, like northern Indiana, has few natural rock exposures and is so deeply covered by drift that the stratified rocks are seldom reached by artificial excavation. It was deemed unwise to allow the opportunity for investigation of the stratigraphy of northern and central Indiana afforded by the active prospecting of last year to escape; and, acting under your direction, I employed Dr. A. J. Phinney, of Muncie, Ind., to collect records of borings in Indiana, to ascertain the distribution of gas, petroleum, etc., in the State, and to develop therefrom the stratigraphy of the region. He was occupied in this work during the months of October, November, and December; and parts of the months of January and February were spent in preparing a report thereon. This report was transmitted to me in March, and after preliminary examination was returned to the author for revision. It will shortly be transmitted for publication as a bulletin of the Survey.

In April last it was learned that a valuable collection of fossils, including many type specimens described and figured by the late David Dale Owen, long preserved in the museum of the State University of Indiana, had, in the exigencies of transfer from place to place and from custodian to custodian, become scattered, partially stripped of labels, and mixed with the educational series of the institution, and also that the university authorities were willing to donate the collection to the Geological Survey or the National Museum if a competent paleontologist were assigned to relabel, and rearrange its remnants. Mr. Marcou was intrusted with the task. He visited the university at Bloomington, assorted, arranged, and relabeled the more valuable fossils, and conveyed them to Washington; and the collection is now accessible to paleontologists in the National Museum. The expenses of Mr. Marcou's trip were, through the courtesy of Prof. G. Brown Goode, in charge of the National Museum, borne by that institution.

*Researches in New York.*—By reason of the considerable time required in the construction of the base upon which the geologic map of New York, described in previous reports, is to be impressed, some progress has been made by Prof. James Hall and others in ascertaining the areal geology of the State since the compilation of the map in 1884; and a visit was made to Albany in December last for the purpose of collecting and incorporating the supplementary

data. Advantage was taken of the opportunity afforded by this trip to examine in greater detail the region of dislocated rocks in the Mohawk Valley, and the complex structure and outcrop of the strata in portions of the tract not previously examined were ascertained. The territory examined includes the valley of West Canada Creek in the vicinity of Herkimer and Middleville, the neighborhood of Palatine church, Fonda and its vicinity, and a considerable tract lying south of Amsterdam. The results of this study have been incorporated in the map, and may also be published in different form.

*Researches in Iowa.*—Some years ago a careful survey was made of the superficial deposits, and incidentally of the Paleozoic strata, of that part of Iowa lying east of the ninety-third meridian and north of the parallel of 41° 30′, a tract of about 16,000 square miles, including twenty-eight out of the ninety-nine counties of the State. The survey was practically completed in 1880, and a draft of a report upon it was prepared; but since the glacial and aqueo-glacial deposits of the tract exhibit topographic characteristics so strongly-marked that the study was one of topographic forms rather than of stratigraphic sequence, it was deemed unwise to publish the report without explanatory and illustrative topographic maps more accurate than any then extant; and the report was accordingly withheld. During the early part of the fiscal year a detailed topographic survey of a representative part of this tract, over 900 square miles in area, centering about Iowa City, was authorized by you, and was executed by the Geographic Division. The survey was made on a scale of a mile to the inch, with a contour interval of twenty feet; and it is represented upon the four atlas sheets bounded by the parallels of 41° 30′ and 42° and the meridians of 91° 15′ and 91° 45′. A few days were spent on the ground with Mr. J. H. Renshawe (who had charge of the topographic survey) early in October last, for the purpose of testing the surveys and ascertaining their sufficiency for the representation of the unique topographic configuration exhibited in this region; and the surveys were found eminently satisfactory.

Early in May a second visit was made to Iowa, for the purposes of working out in detail the structure of the area topographically mapped, reviewing the entire series of phenomena of the tract surveyed in 1878–'80, and revising and completing the report thereon. My own time has been occupied in this work (mainly in the field) during the balance of the fiscal year; and satisfactory progress has been made in its accomplishment.

A simple piece of apparatus, devised to ascertain the succession of unconsolidated deposits in the topographically surveyed area about Iowa City, has been constructed and tested, and found so satisfactory as to merit brief description. It is simply a carpenter's auger, two inches in diameter, welded to a section of half-inch gas-pipe, and provided with a handle, together with a number of interchangeable

sections of gas-pipe of the same size, by which the auger-stem may be extended to any desired length. The sections are joined by thimbles, into which they are screwed in the ordinary manner. Each, including the auger section and the handle, is three feet long. Two pairs of pipe-tongs are required for jointing and unjointing; and the whole apparatus, which weighs less than one hundred pounds and costs about twelve dollars, is packed in a light, portable case. By means of the apparatus two men can put down a bore to a depth of forty or fifty feet, or two bores each twenty to thirty feet, in the course of a day, and satisfactory samples of each stratum penetrated may be brought up and preserved. The device is of course available only in unconsolidated deposits without abundant bowlders.

### OFFICE WORK.

*The Geologic Map of New York.*—As incidentally mentioned in a preceding paragraph, the latest data concerning the areal geology of New York were assembled in December last, and incorporated in the manuscript copy of the map. Meantime the laborious task of preparing the base upon which it is designed to impress the geologic colors has been pushed forward. The western half of this base is completed, and in May it was photographed, and a copy was colored by hand for the use of Prof. James Hall, State geologist of New York, under whose supervision the compila ion was made. The eastern half of the base is approaching completion, and the geologic data are in condition to be then transferred immediately to it.

*Bibliography of Texas, etc.*—This work, which was described in a previous report, and upon which Mr. J. B. Marcou has been engaged during the greater part of the year, is nearly ready for the press. The bibliographic matter is complete, and the index (which will be intercalated with the bibliographic entries) only requires rearrangement for printing. The work is a practically exhaustive annotated and elaborately indexed bibliography of the geology of Texas, Louisiana, Arkansas, and Indian Territory, embracing about 2,500 bibliographic entries, and it will form a volume of 700 or 800 pages.

*The History of American Scientific Surveys.*—The completion of this work has been delayed by reason of the difficulty in obtaining information concerning two or three important surveys whose projectors and conductors are no longer living, and whose records have been mislaid or destroyed. A part of the data lacking a year ago have, however, been obtained during the year; and while the material now on hand is hardly so complete as to warrant publication, it contains a mine of information concerning the State and other surveys of the country, which is accessible to students of the subject. One of the objects contemplated in commencing the work has thus been attained; but it is still the design to secure accounts

of the few surveys concerning which information is yet insufficient, and to prepare the whole for the press as soon as practicable.

*The Thesaurus of American Formations.*—Pressure in other directions has diverted attention from this work, which was described in detail in a previous report, during the greater part of the year; but the original plan has been kept in mind, and some new matter has been incidentally collected and tabulated.

*Record of Progress in Geology, Paleontology and Mineralogy.*—For some years past Mr. J. B. Marcou, of this division, has prepared an annual record of progress in paleontology for publication by the Smithsonian Institution; and Prof. Edward S. Dana, of Yale College, has in like manner prepared annual records of progress in mineralogy for the Smithsonian Institution, and during the fiscal year of 1886–87 Mr. Nelson H. Darton, of the Appalachian Division of Geology, prepared a bibliography of American geology, covering the year 1886, which has already been published as a bulletin of the Geological Survey. During the fiscal year just closed it was ascertained that the Secretary of the Smithsonian Institution had decided to discontinue the publication of the annual records of progress in paleontology and mineralogy; and believing that such records are invaluable to students of these subjects, and that their preparation and publication is germane to the purposes of the Geological Survey, I arranged, with your approval, for the preparation of annotated bibliographic records of progress in paleontology and mineralogy for the year 1887 by Messrs. Marcou and Dana respectively, as nearly as possible in accordance with the plan already adopted by Mr. Darton. These records were completed about the end of March, and transmitted for publication in conjunction with Mr. Darton's similar record of progress in geology in the form of a bulletin, and as an early number in a series of annual records of progress in geologic science, which it is proposed to continue, and perhaps extend over the related fields of petrography, seismology, etc.

*The Report on Natural Gas in Indiana.*—The draft of the report on the geologic structure, natural gas, petroleum, etc., of Indiana, submitted by Dr. Phinney, was hastily prepared and transmitted as promptly as possible for examination and office use, and when publication was decided upon, critical revision of the manuscripts was found necessary. It was then returned to the author for the incorporation of new data. So the manuscripts of text and illustrations have twice passed through my hands, each time receiving critical attention and some modification.

*The Report on Northeastern Iowa.*—As noted in a preceding paragraph, considerable parts of the months of May and June were occupied in the preparation of a report on the geologic structure and superficial phenomena of an area of 16,000 square miles in northeastern Iowa. The tract in question exhibits many features of in-

terest, both scientific and economic; within it the loess of the Mississippi Valley is typically developed in a number of phases, whose relations are such as to indicate the genesis of all; the greater part of it is occupied by two distinct sheets of glacial drift, both of which graduate into aqueo-glacial deposits in a distinctive way, which are separated by an ancient soil and forest bed, and whose relations to the subjacent rocks are displayed with exceptional clearness. The tract includes a part of the "driftless area" of the upper Mississippi Valley, and well illustrates the relation between the local residuary products and exclusively hydric topography of that area on the one hand, and the glacial and aqueo-glacial deposits and topography on the other hand—the marginal phenomena being exceptionally clear and pregnant with data bearing upon the history of the action of ice and water respectively in the Quaternary. The tract is diversified by unique hills and ridges, approaching in form, though not in constitution, the kames of Scotland and the åsar of Scandinavia, and their relations to drift, loess, general topographic configuration, and subjacent rock-surface are such as to clearly indicate their genesis. The behavior of the streams of the tract is anomalous, in that the general direction of the drainage is at right angles to the general slope of surface, and in that the rivers have frequently avoided low-lying plains and valleys, and have cut for themselves deep gorges in neighboring plateaus or in the axes of neighboring ridges; and careful study shows that these various phenomena are intimately related, that in large measure their causes were common, and that their testimony concerning the Quaternary history of the region is consistent and cumulative, and at the same time comprehensive and minute. It is the design to render the report monographic upon these categories of phenomena, and to set forth the geologic history of the tract in considerable detail, and it is the design also to consider carefully the economic bearing of the phenomena, and especially to describe and classify the soils and subsoils of the tract surveyed. Satisfactory progress has been made in the preparation of the report.

It is a pleasure to express indebtedness to President Charles A. Schaeffer, of the Iowa State University, and Prof. Samuel Calvin, of the natural history department, for the use of a commodious room in the natural history building of the university for office purposes.

*Miscellaneous.*—During the year several brief papers were prepared for the press, the most noteworthy being "Three Formations of the Middle Atlantic Slope," published in the American Journal of Science, February, April, May, and June last, and "The Geology of Macon, Mo.," published in volume V of the Transactions of the St. Louis Academy of Science. Part of February and March last were occupied in revising, with Mr. L. C. Johnson, the report by that

gentleman upon the lower tertiary formations of Mississippi; and a considerable part of each of the earlier months of the year was spent in administrative work, official correspondence, etc., under your immediate supervision, which does not require special mention here.

In conclusion, I beg to express my indebtedness to you not only for every facility in pursuing the investigations with which I am charged, but also for the fruitful suggestion, criticism, and discussion with which you have from time to time favored me, and without which my work would assuredly have fallen far short of the value which it may now possess.

I have the honor to be, sir, with great respect, your obedient servant,

W J McGee,
*Geologist in Charge.*

Hon. J. W. Powell,
*Director U. S. Geological Survey, Washington, D. C.*

## REPORT OF MR. L. C. JOHNSON.

Lower Mississippi Division,
*Meridian, Miss., July* 1, 1888.

Sir: Field work for the year just ended was not begun in the division of the Lower Mississippi until October, 1887. There was still much remaining to be done to ascertain the correct subdivisions of the Eocene and their boundaries.

This was commenced by examinations of the upper formations, named by Prof. E. W. Hilgard the Vicksburg and the Jackson. The boundary between these two, as established by him, was found to be sufficiently defined. A prolonged search was required in the counties of Jasper, Clarke, and Wayne, Miss., to ascertain exactly the relation of the Vicksburg Eocene to that extensive fresh-water formation of south Mississippi known as the "Grand Gulf" (Hilgard). This search was finally ended by finding on the Chickasawha River, in Wayne County, some three miles southwest of Waynesborough, a section where the Grand Gulf is seen to repose with apparent conformity upon the rocks of the Vicksburg formation.

This division of the assigned work was completed December 20, 1887, and I repaired to north Mississippi. The Tertiary formations of that portion of the State are covered deeply by Quaternary deposits and constitute the most difficult problem of the stratigraphy of the district. It had been reserved for the principal work of the spring and summer. The month of January, 1888, proved very unfavorable for field operations, and early in February orders were received to repair to headquarters in Washington for office duty. Work upon and in

connection with the reports of the preliminary surveys in Louisiana and Mississippi occupied all the time from February 7 to June 1.

Field work done this month (June) has been towards perfecting a survey of these obscure formations in the northern and eastern portions of the State of Mississippi.

It will appear from the report in your office that something has been accomplished towards clearing away the difficulties which obscured the stratigraphy of this portion of the Gulf States, but much is left uncompleted. Many useful materials have been found to exist abundantly in Mississippi, such as building stone, clay, lime, lignite, and iron, and numerous localities of these are described in the report, and are indicated on the map which accompanies it.

Very respectfully, your obedient servant,

LAWRENCE C. JOHNSON,
*Assistant Geologist in Charge.*

Hon. J. W. POWELL,
*Director U. S. Geological Survey, Washington, D. C.*

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## REPORT OF MR. A. C. PEALE.

MONTANA DIVISION OF GEOLOGY,
*Washington, D. C., July* 1, 1888.

SIR: I have the honor to submit the following report of the operations of the Montana division for the year ended June 30, 1888:

### FIELD WORK.

Upon receipt of instructions early in July, I proceeded to Bozeman, and field work was begun at that place July 14, 1887, with the view to completing the delineation of the geological feature of the northern half of the Three Forks topographical sheet. This was accomplished by September 23, although an unusually wet season somewhat retarded field operations. The latter half of July and the first week of August were occupied in the investigation of a small area extending southward from the Gallatin Valley to about the line of parallel 45° 30′. The junction of the lake beds on the south side of the Gallatin Valley with the gneisses was determined, and trips were made up the cañons of Bozeman Creek, Middle Creek, and Cottonwood Creek, and the relations of the sedimentary rocks overlying the gneiss to the eruptive rocks of the higher mountains farther southward were studied. During the remainder of August the area under examination was that extending westward from the West Gallatin River to the South Boulder Range and lying between the parallels of 45° 30′, and 45° 45′. This area is about equally divided between the Archæan gneisses and the

southwestward extension of the Gallatin Valley lacustrine deposits. The limit of the latter in this direction was outlined, and in connection with the gneissic outcrops several interesting intrusions of igneous rocks were carefully studied. The route followed was southward up the West Gallatin to the mouth of Spanish Creek, and thence westward into Spanish Creek Basin. The West Gallatin River cuts its way into the Gallatin Valley through a gorge of some 1,600 to 2,000 feet in depth, the gneissic walls of the immediate cañon reaching from 600 to 1,000 feet above the level of the stream. Along the mouth of Spanish Creek sedimentary rocks are found, but the basin of Spanish Creek itself is underlaid mainly by gneisses. From this point we proceeded northward, via Cherry Creek and Pole Creek, to the Madison River, below the cañon. Our route took us along the line of junction of the gneisses and the overlying Potsdam sandstone, which rests directly upon them. Between the middle and lower valleys of the Madison the river flows in a rugged gneissic cañon 2,000 feet in depth. This cañon is about fifteen miles in length, and ends a short distance below the mouth of Hot Spring Creek, a tributary coming in from the west. Up this stream we traveled as far as Sterling, which was made the point of departure for the examination of the region lying west and south of this now almost deserted mining town. In this portion of Madison County the quartz mines in the vicinity of Pony and Red Bluff are productive, and with future increased facilities in the matter of transportation the output of the mines will undoubtedly be largely augmented.

The country is dotted with prospect holes, and the town of Pony appears to be at the present time the most important center of mining activity in this part of the Territory. It lies at the head of Willow Creek Valley, which, although small, is one of the most fertile valleys in Montana. The western limit of the lake deposits, which are exactly like those of the Gallatin, lies a short distance beyond this valley, where the beds lap onto the gneisses in the foothills of the South Boulder Range.

The three weeks of September, during which field work was carried on, were devoted to the geological examination of the northwestern portion of the Three Forks sheet; i. e., the vicinity of the Jefferson River, above the Three Forks, or head of the Missouri River. This area is mainly one of sedimentary rocks, the formations from the lower or middle portion of the Cambrian up to the lower part of the Cretaceous all being present. It is a region of some complication, due to the presence of several folds and faults, confused somewhat by the effusion of igneous rocks, the latter being of very great interest. Our knowledge of the Paleozoic section of this portion of the Territory was largely increased by the study of the rocks exposed in this area, and interesting collections of fossils were obtained from the Devonian and Carboniferous portions, which even upon a pre-

liminary examination have considerably enlarged our knowledge of the fauna of those formations for Montana. Thirty-nine species have been identified from the Devonian and sixty from the Carboniferous.

One of the results of the study of this fauna is the development of the fact that there is an apparent mingling of Devonian and Carboniferous forms throughout the central portion of the mountain limestones heretofore regarded as belonging entirely to the Carboniferous. The occurrence of Lower Carboniferous forms very high in the series referred to the Middle Carboniferous is another interesting fact.

The cañon of the Jefferson River is one of the interesting topographical features of this area. Although only about five miles in length, it is about 1,800 feet in depth, and exposes the east section of the East Gallatin group and overlying beds in an exceedingly beautiful manner. The valley of the Jefferson below the cañon for about ten miles is bordered by hills that rise from 1,000 to 1,500 feet above the level of the river, which keeps close to the foot of the hills on the south side, while on the north side the valley gradually becomes wider and wider, until the stream finally flows out into the beautiful valley of the Three Forks, where it unites with the Madison and Gallatin Rivers to form the Missouri.

The route followed through this northwestern portion of our area was from Willow Creek westward across Antelope and South Boulder Creeks along the southern edge of the hills bordering the south side of the Jefferson River until the river was reached above the cañon. From the latter point the North Boulder was followed to a point about eight miles north of the Jefferson, whence we turned eastward, reaching the Jefferson again near the town of Three Forks, a settlement located between that river and the Madison; thence we proceeded, via the Gallatin and West Gallatin Rivers, to Bozeman, where the field party was disbanded for the season.

## OFFICE WORK.

During the year the third paper upon the statistics of mineral waters was published, and a fourth paper upon the same subject, giving the statistics for the year 1887, has been prepared, and is ready for publication in the forthcoming volume of "Mineral Resources." Work upon the manuscript of a bulletin on the Paleozoic section of the northern part of the Gallatin Valley has occupied considerable time. Forty pages of manuscript and four plates for illustration are now ready, and Mr. G. P. Merrill, of the National Museum, has prepared a description of the eruptive rocks of the section, with several illustrations. The bulletin will be ready for publication early in the ensuing fiscal year.

The division is under obligation to the Chemical Division for numerous analyses of rocks furnished; to the petrographic laboratory for thin sections of ninety specimens of igneous rocks; and to Mr. C. D. Walcott for identification of fossils. Mr. Charles W. Richmond has rendered efficient service in the office, especially in the preparation of the paper upon Mineral Waters.

Very respectfully,

A. C. PEALE,
*Geologist in Charge.*

Hon. J. W. POWELL,
*Director U. S. Geological Survey, Washington, D. C.*

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## REPORT OF PROF. O. C. MARSH.

DIVISION OF VERTEBRATE PALEONTOLOGY,
*New Haven, Conn., July* 1, 1888.

SIR: I have the honor to submit the following report of the work of this division during the past fiscal year:

In compliance with your letter of general instructions, I have continued the systematic work of collecting vertebrate fossils and investigating those of special interest to science.

The field work in the West during the past year has been energetically prosecuted, and the results promise to be important. The explorations in the Miocene deposits of Dakota have been continued systematically, and large and valuable collections of vertebrate fossils have been secured. A special search was made for remains of the Brontotheridæ, not merely to secure additional material, which was much needed, but also to ascertain, if possible, the geographical and geological distribution of this remarkable group. A large number of individuals were secured at various localities, and a comparative investigation of these remains has already disclosed important differences, which serve to distinguish both the genera and species, as well as age and sex.

Another important point was clearly established, that the great Miocene basin of Dakota, in which the Brontotheridæ were entombed, may be separated into well-marked horizons, each containing one or more distinct forms of this group. This corresponds with what I had previously ascertained from a study of the great Eocene basin of Wyoming, where special forms of the Dinocerata had each its own horizon.

In the Jurassic deposits of Wyoming work has been continued during the past year with good success. This is true also of southern Colorado, where important collections in essentially the same horizon have been made.

Your special letter of instruction, dated May 13, 1887, requested

me to make a careful examination of the Potomac formation for vertebrate fossils, with a view to determine the age of these deposits, so long in doubt. The western work then in progress made it impossible to begin this investigation before October 1, when I detailed Mr. J. B. Hatcher, one of my most experienced assistants, to commence the examination. Mr. Hatcher's experience in the West proved of great service, and his careful work along the outcrops of the Potomac formation between Baltimore and Washington continued for several months, resulting in important discoveries. Subsequently I went over the ground myself, and visited all the more interesting localities, with a view to determine the horizons of the fossils discovered. The results of the entire investigation proved conclusively that the Potomac formation, as shown in its typical localities in Maryland, is of Upper Jurassic age, and contains a rich and varied vertebrate fauna. This fauna is distinct from any hitherto discovered, but corresponds most nearly to that of the Atlantosaurus beds in the Rocky Mountain region.

The work at New Haven during the past year on the monographs now in preparation has made systematic progress. The investigation of the large collections of the remains of Brontotheridæ has been continued with important results. The illustrations for the monograph on this group, consisting of sixty lithographic plates and one hundred and fifty wood-cuts, have been finished and all sent to the Public Printer. This has delayed somewhat the publication of the volume on the Sauropoda, which will soon be completed.

Very respectfully,

O. C. MARSH,
*Paleontologist in Charge.*

Hon. J. W. POWELL,
*Director U. S. Geological Survey, Washington, D. C.*

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## REPORT OF MR. C. D. WALCOTT.

DIVISION OF PALEOZOIC INVERTEBRATES,
*Washington, D. C., July* 1, 1888.

SIR: I have the honor to present the following report of operations conducted under my charge during the fiscal year ended June 30, 1888:

### FIELD WORK.

The field operations for the year were: (1) The continuation of the study of the geology of Washington County, N. Y., and the extension of the mapping of the strata of that county into and across Rensselaer County, N. Y., to the Columbia County line; (2) the examination of the strata of the Taconic Range in western Mas-

sachusetts and southwestern Vermont; (3) the study of certain strata in Schoharie County, N. Y.; (4) the examination of Cambrian strata in the vicinity of North Attleborough, Mass.; (5) the collecting of fossils from the Chazy terrane, at Fort Cassin, Vt., and also from the Trenton and Hudson terranes of central New York.

During the field season of 1886 I studied and mapped the geologic terranes of about two-thirds of the area of Washington County, N. Y. The first work of the present year was to complete the map of the county and to verify a number of observations made in 1886. This was accomplished, and I then traced the formations found in the county south into Rensselaer County and onward to the Columbia County line, and secured the data for compiling a geologic map of Rensselaer County. One of the objects of this work was to obtain data for the purpose of determining what was originally included in the "Taconic System" by its author, Dr. Emmons; another was to make a geologic map of the two counties that could be incorporated with the New York State geologic map, in preparation under the charge of Mr. W J McGee. The boundaries of the various geologic formations were determined and the geologic horizon of each of them fixed by the discovery of numerous localities where characteristic fossils occurred. At various times during the field season I crossed into Vermont, and also into Massachusetts, so as to cross-section the entire Taconic area to the pre-Cambrian rocks of the Green Mountains, upon which the lowest member of the Cambrian system rests on the east.

The stratigraphy of the eastern portion of this area was found to be essentially as described by Dr. Emmons, but the finding of fossils in the quartzite on the east, and also in the overlying limestones, proved that he had misinterpreted the geologic age of the greater portion of the original "Taconic System." The study of the strata, included in the "Upper Taconic" by Dr. Emmons, proved that he had included a great mass of the Hudson terrane in the "Upper Taconic," and also that he had made errors of observation along the line of contact of the rocks of the Lower Silurian terrane with those of the Cambrian. At all localities given by him I found that the Cambrian rocks were thrust over onto the Lower Silurian rocks; and in no instance did I find that the latter rocks, either by original deposition or by subsequent dislocation, were above or on the strata belonging to the Cambrian system.

One result of the study of the geology of Washington County has been the determination of a thickness of Cambrian strata greater than all sedimentary rocks heretofore known in the State of New York above the horizon of the Potsdam terrane. The sections are not yet completed, but I think that more than 16,000 feet of strata may be referred to the Cambrian.

The data obtained in the study of the strata of the Hudson ter-

rane enables me to state that that terrane has a thickness of over 6,000 feet in the valley of the Hudson, and also that it is composed of several quite distinct formations, characterized by their lithology. At the close of the field season I visited localities in Schoharie County, N. Y., for the purpose of examining the section of the Hudson terrane so well exposed in the vicinity of Knowersville. The exposed section and the record of a deep well prove that it has a thickness of over 3,000 feet at the latter place.

In May, in company with Prof. N. S. Shaler, I visited the localities of Middle Cambrian rocks discovered by him near North Attleborough, Mass., and also looked over the comparatively large series of fossils which had been collected under his direction. The discovery of this area of Cambrian strata is of unusual interest, as it gives a datum point in the midst of a large scope of unidentified strata, and also affords important information in relation to the distribution of the Cambrian fauna.

During the month of June I re-examined with care the lower portion of the Cambrian section in the township of Greenwich, as well as the upper portion in the township of Salem, Washington County, N. Y.

Mr. Ira Sayles was instructed to collect fossils from certain localities in Washington County, and he was thus engaged in field work until late in October.

One of the important results of the field work of the year was the collection, by Mr. W. P. Rust, of a large series of fossils at Fort Cassin, Vt., from the Chazy terrane. He also collected a large quantity of material in the vicinity of Watertown and Middleville, N. Y.; these being the typical localities from which were obtained most of the fossils described as from the Trenton limestone in the first volume of the Paleontology of New York. The result of this work is represented in the large collection sent in by Mr. Rust, after he had carefully worked up the material ready for study or exhibition. This collection includes:

| | Specimens. |
|---|---|
| Chazy terrane | 1,570 |
| Trenton terrane | 2,914 |
| Hudson terrane | 667 |
| Total | 5,151 |

Prof. Henry S. Williams reports that owing to the pressure of work connected with his duties at Cornell University he was not able to do much field work during the past season, but that he did accomplish something in the vicinity of Cayuga Lake and in Chautauqua County, N. Y.

Mr. Robert T. Hill was assigned to this division as an assistant, but with the exception of being with me for ten days in August, in western Massachusetts, his time was given to work in connection with the Geological Survey of Arkansas.

When east, in May, I visited Boston and Cambridge, Mass., and examined certain collections of Cambrian fossils in the Museum of Comparative Zoology at Cambridge and in the rooms of the Boston Society of Natural History at Boston. On my return trip to Washington I stopped a few hours to see the collections of Paleozoic fossils at the Peabody Museum, New Haven, Conn.

By verbal direction I met you at the meeting of the American Association for the Advancement of Science, in New York City, August 10, for consultation and to be present at the meeting of the Geologic Section. I there gave a brief notice of the work accomplished by me on the Cambrian rocks of southern Vermont and northwestern Massachusetts, and also read a paper on a deep well, drilled in the Silurian and Cambrian rocks of Oneida County, N. Y.

## OFFICE WORK.

Prof. Henry S. Williams has continued the elaboration of the collections of Devonian fossils, made in previous years, with the identification of the fossils and comparison of the faunas. His report on the Genesee section, across New York State, has been published as Bulletin No. 41.

The general bearing of his studies upon the unifying of nomenclature and classification has been discussed in a report to the International Congress of Geologists.

Through the assistance of Mr. Ira Sayles locality labels were affixed to a large part of the Devonian material collected by Professor Williams, and a good start was made in packing duplicate material preparatory to sending it to the National Museum.

On my return from the field, in November, I began the preparation of a paper on "The Taconic System of Emmons, and the use of the name Taconic in geologic nomenclature." This, with the routine work of the office and the study of material from the Cambrian system with relation to the succession of the Cambrian faunas, occupied my time until leaving for the field in the latter part of May.

Early in May I began work on the identification of a collection of Devonian and Carboniferous fossils which were collected by Dr. A. C. Peale in Montana. This was completed, and the lists were furnished to Dr. Peale May 22.

A small collection of Devonico-Carboniferous fossils from Colorado was examined for Prof. S. F. Emmons, and a note thereon sent to him.

Mr. Ira Sayles was engaged in unpacking and arranging the material collected by him during the field season until February, when he was detailed to assist Prof. Henry S. Williams, at Ithaca, N. Y., in placing record labels on the specimens belonging to the U. S. Geological Survey and in packing the duplicates. This work was not completed at the close of the fiscal year.

Mr. A. D. Duganne was employed during April and May in unpacking the collections sent in by Mr. William P. Rust and affixing record labels to them.

Mr. J. W. Gentry remained in charge of the office during my absence in the field. He made progress in the compilation of a card catalogue of Paleozoic fossils. During the whole year he attended to the general clerical work of the division.

As honorary curator, in charge of the collections of the invertebrate Paleozoic fossils of the U. S. National Museum, my attention was given at various times during the year to the arrangement of the collections; and in May a series of fossils was placed in the exhibition cases through the aid of Mr. R. R. Gurley, Museum assistant. This series includes, from the

| | Specimens. |
|---|---|
| Cambrian | 1,331 |
| Lower Silurian | 2,736 |
| Upper Silurian | 1,711 |
| Devonian | 2,076 |
| Carboniferous | 3,101 |
| Total | 10,955 |

The following material was transferred from the Survey collections to those of the Museum: (1) One specimen from Mr. C. E. Beecher, Albany, N. Y., from the Lower Helderberg terrane of the Silurian system; (2) one box of geologic specimens, secured by me from Lake George, N. Y.; (3) the collection of Mr. L. J. Bennett, Buffalo, N. Y. containing twenty-nine specimens from the Waterlime terrane of the Silurian system; (4) fifty-two specimens from the Cambrian system, from my own collections.

As in previous years, the Director of the Museum provided the necessary facilities for the care of the collections.

More room for the proper storage of the unworked collections of the Geological Survey is necessary. Collections once unpacked for preliminary examination should not be repacked and again unpacked before they are studied. The final study of the collections from any given geologic area can not well be taken up until the geologists have completed the field work within such area, and, as this work often extends through several years, and they wish a preliminary report upon the collections of each year, the necessity of having the material in accessible storage cases is very urgent.

The following publications, made on the results of studies carried on in this division, appeared during the year:

Note on the Genus Archæocyathus of Billings; Charles D. Walcott, Am. Jour. Sci., vol. 34, August, 1887; 2 pages.

Fauna of the "Upper Taconic" of Emmons, in Washington County, N. Y.; Charles D. Walcott, Am. Jour. Sci., vol. 34, pp. 187–199, pl. i, September, 1887.

Section of Lower Silurian (Ordovician) and Cambrian Strata in central New York, as shown by a deep well near Utica; Charles D. Walcott, Proc. Am. Assoc. Adv. Sci., vol. 36, 1887, p. 212.

Discovery of Fossils in the Lower Taconic of Emmons; Charles D. Walcott, Proc. Am. Assoc. Adv. Sci., vol. 36, 1887, p. 213.

The Taconic System of Emmons, and the use of the name Taconic in Geologic nomenclature; Charles D. Walcott, Am. Jour. Sci., vol. 35, pp. 229–242, March, 1888; pp. 307–327, April, 1888; pp. 394–401, May, 1888, (a total of 43 pages), with 13 figures and map.

Respectfully,

CHARLES D. WALCOTT,
*Paleontologist in Charge.*

HON. J. W. POWELL,
*Director U. S. Geological Survey, Washington, D. C.*

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## REPORT OF DR. C. A. WHITE.

DIVISION OF MESOZOIC INVERTEBRATES,
*Washington, July* 1, 1888.

SIR: I have the honor to make the following report of the office and field work which has been done by the division of the survey in my charge during the fiscal year ending June 30, 1888:

The office work of the division occupied all the time from July 1 to October 4 inclusive. This work consisted of the study of the fossil collections which have been made by this division as well as of others made by members of other divisions, in the preparation of a part of the results of those studies for publication, in writing up the results of previous investigations and in the ordinary routine office work.

On October 5, in accordance with your instructions, I proceeded to Texas, for the purpose of resuming the investigations in the field which I had prosecuted there in the preceding year, taking with me my assistant, Mr. C. B. Boyle. From the city of Dallas, as a center, I extended these field observations into the neighboring counties of Tarrant, Denton, Kaufman, and Navarro. This work consisted of an investigation of the stratigraphic relations of the formations occurring in that region with one another and with those of other regions; and it also embraced a study of their paleontological characteristics.

The special object of this work was to ascertain as clearly as possible the relation between the Cretaceous formations which occur in Texas with those which are found to the eastward, westward, and northward of that region respectively. The result has been in a high degree satisfactory, but much yet remains to be done in that connection. I was able, on paleontological grounds, to correlate the upper formations of the Cretaceous series in that part of Texas with the Rotten Limestone and Ripley formations of Mississippi and Alabama with an unexpected degree of clearness. Besides this, a part

of the series beneath these upper formations are now regarded with nearly equal confidence as equivalent with certain of the formations of western Texas and of the great interior region which stretches to the northward. The basis of these latter correlations was in large part paleontological; but lithological characters, as well as the order of the superposition of the formations, received due consideration.

In connection with this field work important collections of fossils were made, which have not only served their purpose in the correlation of the formations which has just been referred to, but they contain many forms not heretofore known.

I employed Mr. W. F. Cummins in this work as temporary field assistant; and his familiarity with that region and its geology greatly facilitated its progress.

From Dallas I proceeded to Eagle Pass, for the purpose of ascertaining, if possible, the relation of the southern continuation of the great Laramie group with the marine Tertiary formation of the Gulf coast region. Procuring an outfit for field travel at Eagle Pass, I proceeded southward from that place upon the Texan side of the Rio Grande, making my observations by the way. The strata exposed in the hills about Eagle Pass, which consist mainly of sandstones, but which bear one or more beds of coal there, I had previously correlated with the Fox Hills group of the Cretaceous series which so extensively prevails to the northward. These strata were found to dip gradually in the direction of the course of the river and to receive upon them those of the Laramie group. The strata of the Laramie group were found well exposed along the banks of the Rio Grande, from twenty-five to thirty miles above Laredo, where, like the underlying formation, they contain one or more workable beds of coal. They also occur on the Mexican side of the Rio Grande, where characteristic Laramie fossils have been found.

These Laramie strata on both sides of the Rio Grande were found to dip gently to the southeastward, as the underlying formation had been seen to do, and to receive upon them, in the neighborhood of Laredo, sandy strata, which bear an abundance of characteristic marine Eocene fossils. The bearing and importance of these observations I have pointed out in a published article, the title of which is given among others at the end of this report; and I shall have frequent occasion to refer to them in the course of my subsequent work.

After completing the field observations which I had undertaken in the region round about Laredo I returned to Washington, arriving on the 14th of November. Office work was resumed and continued until April 5, 1888. This latter work consisted in elaborating the results of the field work just completed and in studying the fossil collections which had been made by myself and my assistants, as well as those made by members of other divisions of the survey.

On April 5, in accordance with your direction, I proceeded to the Gulf States east of the Mississippi River, for the purpose of pursuing field observations there, taking, as before, Mr. Boyle with me. This work, besides being a continuation of that which I had done in previous years in Texas and elsewhere, had an additional object. This was to accumulate data by personal observation for a work which I am preparing on the Cretaceous of North America, and which I had undertaken after the close of my last field work in Texas.

These observations were made at numerous localities along the trend of the Cretaceous formations as they are exposed in the States of Mississippi, Alabama, and Georgia, and embraced a review of the whole Cretaceous series exposed in those States and its relations to the underlying and overlying formations. Upon the completion of this field work we returned to Washington, arriving on April 30, when office work was again resumed. This latter work consisted mainly in the collation of the data necessary for the preparation of the memoir on the North American Cretaceous, before referred to, for publication.

On May 17, in accordance with your directions, I resumed field operations similar to those which I had made in the Gulf States, and for a similar purpose. These observations were carried through portions of the States of Maryland, Delaware, Pennsylvania, and New Jersey, and continued upon Staten Island, Long Island, and Martha's Vineyard. In this journey the principal Cretaceous localities in the States named were visited, as well as a number of localities where strata are exposed, concerning the Cretaceous age of which geologists differ in opinion. I returned to Washington on June 4, again resuming office work, which was continued until June 30.

During the past fiscal year I have prepared for publication a number of articles which contain results of my geological and paleontological studies. The following is a list of their titles, together with the places of their publication:

(1) Bulletin of the U. S. Geological Survey (No. 51), under the general title, "On invertebrate fossils from the Pacific coast," together with fourteen plates of illustrations, and with the five following subordinate titles:

- (*a*) New fossil mollusca from the Chico-Téjon series of California.
- (*b*) The occurrence of equivalents of the Chico-Téjon series in Oregon and Washington Territory.
- (*c*) Cretaceous fossils from the Vancouver's Island region.
- (*d*) The molluscan fauna of the Puget group.
- (*e*) Mesozoic mollusca from the southern coast of the Alaskan peninsula.

(2) Remarks on the genus Aucella, with especial reference to its occurrence in California. (Appendix to Chapter V of Monograph XIII, pp. 226–232, Pls. III, IV.)

(3) On the relations of the Laramie group to earlier and later formations. (Am. Jour. Sci., 3d series, vol. 35, pp. 432–438.)

(4) On the occurrence of Later Cretaceous deposits in Iowa. (Am. Geologist, vol. 1, pp. 221–227, April, 1888.)

(5) Mountain upthrusts. (Am. Naturalist, vol. 22, May, 1888, pp. 399–408.)

(6) On Hindeastræa, a new generic form of Cretaceous Astræidæ. (Geol. Magazine, Decade III, vol. 5, pp. 362, 363.

(7) On the geology and physiography of a portion of northwestern Colorado and adjacent parts of Utah and Wyoming. (Ninth Annual Report of the Director of the U. S. Geological Survey.)

All of which is respectfully submitted.

C. A. WHITE,
*Geologist in Charge.*

Hon. J. W. POWELL,
*Director U. S. Geological Survey, Washington, D. C.*

## REPORT OF MR. W. H. DALL.

DIVISION OF CENOZOIC INVERTEBRATES,
*Washington, D. C., July* 1, 1888.

SIR: I have the honor to report herewith on the operations of the Division of Cenozoic Paleontology during the fiscal year commencing July 1, 1887.

For the constant and cordial cooperation which you have always extended to me in the work under your direction, as to all others similarly employed, I can not refrain from expressing my gratitude and appreciation.

### FORCE.

The force of the division has comprised, besides the writer, Dr. R. E. C. Stearns and Mr. Frank Burns, besides Messrs. Stuart and O'Connor, temporarily employed for brief periods.

### ROUTINE WORK.

The routine work of the division consists in part of paleontological identifications made for other divisions of the Survey, or at the request of the Director for other persons; and, secondly, of the work of cleaning, assorting, classifying, naming, cataloguing, labeling, and arranging for easy reference the fossils collected by the members of the Survey from Tertiary deposits. This second branch of the work is that which requires the most labor, much of it of a clerical kind, and especially because, when I took charge of this division, there was an enormous amount of material, accumulated from previous years, on which no work had been done. This part of the work had also been hampered by the want of sufficient room to spread out the fossils or have easy access to those which are not directly under treatment. The work has been facilitated by assist-

ance rendered, with the permission of the Director of the National Museum, by Mr. P. L. Jouy, aid to the Museum for the department of recent and fossil Tertiary mollusks. The work on the two kinds of material being necessarily synchronous, it has been conducted simultaneously, to the benefit of both the Survey and the Museum. The material referred to the Division for examination and report has in all cases been promptly attended to, and there are no arrears of this kind. The final registrations for the year 1886–'87 were 10,530 entries, equivalent to about 32,000 specimens; for 1887–'88 the total is 11,803, corresponding to about 35,400 specimens. But it should be remembered that this work was done with less clerical assistance than that of the previous year, as during fully half the year this division has been without any competent or trustworthy clerk, while in 1886–'87 there was no such deficiency.

## FIELD WORK.

Field work has been carried out by the division in California, Florida, and New Jersey. In August, September, and October Dr. Stearns was engaged on an investigation of the supposed Pliocene deposits of southern California, near the Mexican boundary, and San Diego, Cal., shipping sixteen boxes of fossils to Washington.

In October, hearing from Prof. R. P. Whitfield, who is engaged on a report on the Miocene paleontology of New Jersey, especially the fauna of the marls, that he was hampered by an insufficiency of material, I sent Mr. Frank Burns to the marl region near Bridgeton, N. J., where, after a stay of four or five weeks (October–November, 1887), though much impeded by rains, he was able to supply Prof. Whitfield with twelve boxes of fossils, including many which that gentleman had not before received. Later in the season (June, 1888) I visited the locality to determine the geological aspect of the deposits, which I was informed by Professor Cook, State geologist of New Jersey, was not well understood or anywhere fully described. A short stay enabled me to secure the desired data.

In February, in pursuance of the instructions received from you in regard to a general review of our Plio-Miocene formation, I sent Mr. Burns to Tampa, Fla., with instructions to collect as fully as possible the fossil fauna of the silex beds of Ballast Point and vicinity and to determine their extent, and subsequently to endeavor to trace the sequence of the Tertiary strata at the surface along the line of the Florida Southern Railway between Lakeland and Charlotte Harbor, at Punta Gorda.

He remained in the field until May in spite of the yellow fever, alleged to be lurking about Tampa, and then returned with a fine collection of the silex fossils and numerous notes on the points to be

investigated, but nothing absolutely decisive, the ground being obscured by deep beds of sand and Post-Pliocene deposits and raised but little above the sea level.

Meanwhile we have had the kind cooperation of Mr. Joseph Willcox, who has been exploring the Floridian geology year by year on his own account, adding very largely to our knowledge of the distribution of the fossil fauna as well as the extent of the respective formations. During the winter Mr. Willcox has demonstrated the presence of the Pliocene farther north and the Miocene farther south than had been previously reported. He also found in the northern part of the Everglades coral-limestone of the nature of that described by Agassiz on the Keys, while showing that this kind of coral rock does not extend beyond the Everglades northward in the region traversed. A report on these rocks and their fauna, based on the collections of the Survey and those made by Mr. Willcox, is already somewhat advanced, and will, it is supposed, be completed during the next half year.

## COOPERATIVE WORK.

The policy of enlisting the interest, and as far as possible the activity, of individuals not officially connected with the Survey in supplementing and extending its work is one that is its own recommendation. In no other way can so much be accomplished which is desirable for science without expense to the Government.

In addition to the material put into the hands of Professor Whitfield to enrich his means of study as above referred to, and the cooperation with Mr. Willcox in the exploration of Florida, the Division of Cenozoic paleontology has been able to enlist the sympathy and services of Mr. T. H. Aldrich, who is at work on the Alabama Tertiaries and the Eocene formation in particular. He has been furnished with material for study and has contributed named material for the easier identification of our specimens at the Museum. Mr. Aldrich is having the original type specimens of Say, Conrad, and other early writers carefully figured, and the results of his studies will doubtless be important for American paleontology. The division has also co-operated with the Johns Hopkins University through its member, Mr. W.B. Clark, who is working up the Maryland Tertiaries, and to whom named duplicates have been sent to assist him in his identifications. Named duplicates have also been furnished the Wesleyan University at Middletown, Conn., through the National Museum, and material for study has been furnished Dr. Joseph Leidy, of Philadelphia.

The writer has also, at the request of the Secretary of State, placed his special knowledge of Alaskan geography and history at the disposal of the Department, and has engaged in several conferences on subjects connected with the settlement of the question of the bound-

ary between the territory of Great Britain and the United States in Alaska and the Northwest Territory.

The cooperation between the division and the U. S. National Museum, authorized by yourself and the late Professor Baird, has continued, as heretofore, with beneficial results.

The late Dr. Isaac Lea left his collection of minerals, fossils, and mollusks to the Museum, a collection of great interest to the Survey, not only as containing part of Dr. Lea's types of original fossils described by him from Alabama in 1836, but as containing a fine series of foreign Tertiary species, of British Mesozoic species, many Paleozoic, especially Coal Measure fossil animals and plants, and even a series received from Dr. Emmons himself of several of the primordial fossils from the original Taconic formation so long and bitterly disputed. The value of these things being largely dependent on the preservation of their labels and identity, I went to Philadelphia on two occasions to supervise the proper packing, in the course of which work, to prevent loss of identification, I placed on the specimens themselves—of which there are some 20,000—more than 85,000 written figures, and registered in the catalogue over 3,000 typical specimens, representing about half as many species. This collection, exclusive of duplicates, occupied some sixty packing boxes, and is now safely deposited in the Museum. This work was extremely tedious and wearing; but it was well worth the trouble to preserve the value of this unique series.

## WORK OF RESEARCH.

The regular routine and other work above described, in the absence of sufficient clerical assistance, has left little time for original research. However, investigations have been in progress on the Plio-Miocene of Florida, of which four or five hundred species have been discriminated and in part compared with their recent descendants. An interesting fauna of Miocene land shells has been discovered in the silex beds, and the lineage of several well-known species of marine shells has been traced from the Eocene to the living representatives of the present day. This work will probably be completed during the year.

A visit to the marl beds of southwestern New Jersey has resulted in showing that above the barren black sand of unknown depth which forms the base of the marl series there are three successive, unconformable, distinct strata of marl. The bottom stratum or "shell marl" is eight or ten feet thick, blackish when wet as it lies in the bed, of a grayish-green when dry, with numerous rolled fragments and broken pieces of white fossil shells scattered through it. With these fragments are occasional complete specimens of Astarte, Crassatella, Turritella, Balanus, etc., with occasional sharks' teeth

and other vertebrate remains. The upper surface of the beds is very irregular, showing evidences of denudation in the rounded hummocky surface, and the whole bears evidence of having been deposited in a region of disturbed water, where most of the fossils were carried by currents and irregularly mingled. A similar deposit, biologically, is now forming in the sea off Cape Hatteras at a depth of thirty to fifty fathoms.

Above the shell marl and unconformably filling its concavities is the "black marl," destitute of fossils, and clayey or unctuous in feel. Of this there are two or three feet on the average, and the upper surface is irregularly rounded and worn into lumps like the shell-marl surface below. Above the black marl is the "yellow marl," also chiefly destitute of fossils and unconformable with the black marl below it. It is less unctuous, but rather greasy, of an orange-brown color, and does not average over two feet in thickness, and is sometimes absent or even indicated only by a narrow yellow line. It also has an irregularly rounded worn surface. Over this lies ten feet of fine sandy drift gravel without fossils, capped by six inches of vegetable mold. The marl lies in patches of comparatively limited extent, but the succession near Shiloh, at Marlborough and Jericho, was essentially the same in all the pits and sections. It is quite within the limit of possibility that the vertebrate animals whose bones and teeth are found in the marls did not live at the time those marls were being deposited, but were the relics of a preceding epoch, like the Miocene fossils now being mixed with sharks' teeth and the recent fauna in the deposit of the North Carolina coast, of which specimens have been dredged up by the Fish Commission. In that deposit the teeth of recent and of Miocene sharks are indiscriminately mingled, and, were it consolidated into rock, they would present no distinguishing characters by which the formation could be distinguished from one of Miocene or Pliocene age.

I have called attention to these facts here as being of general interest, though too brief in sum to form the subject of a report by themselves.

Very respectfully,

Wm. H. Dall,
*Paleontologist in Charge.*

Hon. J. W. Powell,
*Director U. S. Geological Survey, Washington, D. C.*

## REPORT OF MR. LESTER F. WARD.

DIVISION OF PALEOBOTANY,
*Washington, D. C., July* 1, 1888.

SIR: I have the honor to submit the following report of the operations of the Division of Paleobotany during the fiscal year:

### FIELD WORK.

On July 28, 1887, pursuant to your instructions, I left Washington, and, accompanied by Prof. F. H. Knowlton, of the U. S. National Museum, proceeded to Bozeman, Mont., where an outfit was secured for an expedition to the National Park. The outfit consisted of a two-horse team and driver, one general field hand, and three saddle-horses. For my general field assistant I was fortunate in securing the services of Mr. E. C. Alderson, deputy sheriff of Gallatin County, a very active and intelligent man, thoroughly familiar with that country and skilled in every form of wood-craft, mountaineering, and field operation. The expedition left Bozeman on August 3 and proceeded to the National Park, stopping at several points to study the deposits in and around the Bozeman coal mines. A day was spent on Elk Creek, near Yancey's, investigating certain erect silicified trunks and leaf beds at that place, and on the 12th camp was established on Amethyst Creek, left bank of the East Fork of the Yellowstone. The next seventeen days were spent in a careful study of the extensive fossil forests along the slope of Amethyst Mountain, especially the spurs known as Fossil Forest Ridge and Specimen Ridge, and in making large collections not only of leaves, fruits, and other vegetable organs preserved in the stratified ledges between the deposits of breccias and conglomerates that chiefly make up the mountains of this section, but also of sections of silicified wood, so profusely strewn over the country, and of petrified trunks, found in an erect position at nearly all points. Professor Knowlton made this latter branch of the work a specialty, and excursions were made to many points at which such material was to be found. Three days (August 27–29) were spent in making a reconnaissance eastward as far as Cooke City, Mont., for the purpose of observing the extent of the volcanic Tertiary in that direction. The fossil forests were seen to continue along the slopes of Druid Peak, Mt. Norris, Abiathar and Baronette Peaks, a short distance beyond the last-named of which, and near the Park boundary, the Carboniferous limestone beds rise into prominence, and the volcanic beds at length become limited to the basaltic cap constituting the higher peaks.

On August 30 I sent the wagon, with the fossils already collected, in charge of Professor Knowlton, to Gardiner, where they were boxed

up for shipment, and, taking with me Mr. Alderson and an extra horse, with ten days' rations, I undertook a reconnaissance up the East Fork and Miller Creek and eastward to the country known as the Hoodoo Land, outside the Park limits; thence southwestward to the valley of the East Fork, up Cold and Mist Creeks, and over the divide into the valley of Pelican Creek; thence southward along the base of the mountains to the east of Yellowstone Lake, around the head of the South, Southwest, and Flat Mountain arms of the lake to the Lake Geyser on the West Arm; thence across the Continental Divide to the Upper Geyser Basin, where the remainder of the party with the wagon were awaiting us, and which place we reached on September 8. On the following day the party was again divided, Professor Knowlton and Mr. Alderson proceeding by way of the lake shore and the remainder of the party by the wagon road to Sulphur Mountain, from which point the expedition left the Park by the most practicable route, and, after having prepared the collection for shipment from Cinnabar, the railroad terminus, proceeded to Bozeman, and gave up the outfit on the 17th.

The scientific results of the season's work will be reported upon in detail in a separate paper, and it need only be stated here that they were very important and highly satisfactory, and will form the basis for a thorough study of the fossil flora of the National Park.

## OFFICE WORK.

The force of the division has consisted of Messrs. C. D. White and D. W. Cronin, who have remained continuously during the year; Miss Annie S. Moorehead, who remained only through the months of July and August; Mr. G. W. Stuart from July 6 to 31, 1887; Mr. J. L. Bowdre, from October 3, 1887, to May 31, 1888; Miss L. M. Schmidt, from September 28, 1887, and Mr. F. von Dachenhausen, from January 16, 1888, to the present time.

The routine work of the office has consisted chiefly in making drawings of Laramie plants, in preparing a general bibliography of paleobotany, and in completing the species index of fossil plants. Mr. C. D. White has had general supervision of the drawing, and has undertaken to complete the bibliography, which it has been decided to publish separately as soon as it is ready. Messrs. Cronin and von Dachenhausen have made many drawings, and those of the dicotyledonous leaves which were originally selected as types were completed on May 18. Photographs of these drawings have been made and one set has been mounted in groups on large cards and swung in frames to a pillar such as the Museum uses for exhibiting pictures, etc. Another set has been mounted singly on small cards and arranged like a library card-catalogue. This system has been adopted as the most convenient that could be devised for the study and identification of the fossil plants.

A good beginning has been made in delineating the lower forms (Cryptogams, Gymnosperms, and Monocotyledons), and with the present force continued, the work on the Laramie flora will be completed before the end of this fiscal year.

The cataloguing of paleobotanical works for the species index has been done by Miss Schmidt, Mr. Bowdre, and Mr. Stuart, and a large number of slips have been added. Besides these duties Miss Schmidt has assisted me as type-writer operator in the preparation of manuscript and in the correspondence of the office, and Mr. Bowdre has given much time to the binding of pamphlets, packing fossils, and other general work.

On my return from the field in September I resumed work on the general compilation of paleobotanical data. Owing to the diffused condition of the literature I found it necessary to adopt some system by which reference to all the works on any given subject might be more easily made, and after careful consideration I decided to prepare an index of titles which should show the geographical position and geological horizon to which each memoir, article, or work is devoted, and also such other special topics as constitute its principal subject. I gave all my spare time to this work and completed it on February 15. Since that time, as additional titles are found by Mr. White in his researches, he enters them up in the title index before distributing the cards.

On December 27 I withdrew my manuscript on the Geographical Distribution of Fossil Plants, which had not yet gone to press, and revised it thoroughly, which occupied my time until February 9.

The remainder of the year I have devoted in the main to the collection of data relating to the correlation of American plant-bearing deposits, in accordance with the plan which you have authorized. For special reasons I gave precedence to the Potomac formation, and worked up the geographical distribution of its flora from the unpublished monograph of Prof. William M. Fontaine. Having completed this, I began with the lowest formation and have now completed tables of distribution of the Cambrian, Silurian, and Devonian floras. I hope to complete the Carboniferous and submit a paper upon the Paleozoic for publication in the Ninth Annual Report of the Survey.

Prof. Leo Lesquereux, in addition to his duties in identifying specimens sent to him, has completed his work on the flora of the Dakota group, and submitted it for publication. It will form a fair-sized monograph of the Geological Survey, containing fifty-seven quarto plates.

Prof. F. H. Knowlton has caused to be prepared a large number of sections of fossil wood from the National Park. Before entering, however, upon the systematic study of the material in his hands he desired to revisit the Park and make further collections. Accord-

ingly, with the co-operation of Mr. Arnold Hague, in charge of the geology of the Park, he left Washington on the 26th ultimo for Bozeman. He will proceed to the Park this month and make a very thorough study of the country from his special point of view.

A collection of fossil leaf prints from Bridgeton, N. J., probably of Pliocene age, was made during the year by Mr. Frank Burns and sent to me for identification. Not having time at present to take it up, I have, with your authorization, sent it to Mr. John I. Northrop, of Columbia College, New York, who has also made a collection from the same beds, and who desires to undertake the study of fossil plants. He will do the work under the supervision of Dr. J. S. Newberry, and the results will be published by the Survey.

Very respectfully, your obedient servant,

LESTER F. WARD,
*Paleontologist in Charge.*

Hon. J. W. POWELL,
*Director U. S. Geological Survey, Washington, D. C.*

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## REPORT OF PROF. J. S. NEWBERRY.

COLUMBIA COLLEGE, *New York, July* 1, 1888.

SIR: I have the honor to report that my work for the U. S. Geological Survey during the past year has been as follows:

(1) I completed and forwarded to your office, in August, 1887, my monograph of "The Fossil Fishes and Plants of the Triassic Rocks of New Jersey and the Connecticut Valley." It contained figures and descriptions of all the species of fishes and plants up to the present time found in the Triassic areas of the northern Atlantic States, and consisted of about two hundred and forty pages of manuscript, with twenty-six quarto plates, one of which was double.

(2) I finished and submitted, in April, 1888, a monograph of the Paleozoic fishes of North America, prepared at your request. It consisted of about four hundred pages of manuscript, with forty-five quarto plates, of which five are double.

(3) I spent the month of September, 1887, in Colorado, studying the Laramie group and gathering a large amount of material, specimens, and facts for the continuation of the memoir "On the Cretaceous and Tertiary Floras of Western America," on which I have been engaged for many years. For this memoir I have prepared a large amount of manuscript and about one hundred and fifty quarto plates. I hope to have it finished by the end of the present year. To do this it will be necessary for me to make another trip to Colorado, and to have perhaps fifty more plates drawn, for which the material is mostly at hand.

(4) The memoir which I have been preparing for the Geological Survey on "The Flora of the Amboy Clays of New Jersey" is in an advanced stage of progress. All the material yet collected has been studied, and drawings have been made, which form fifty quarto plates. This work also I hope to have completed during the coming year, although the flora which it illustrates has proved to be remarkably rich and interesting, and it is highly desirable that further collections should be made in a field so accessible and one which promises to contribute so much to our knowledge of the history of the ancient vegetation of our country.

I may add that the type specimens described in the memoirs I have mentioned will be, as far as possible, deposited in the National Museum.

Yours, respectfully,

J. S. Newberry.

Hon. J. W. Powell,

*Director U. S. Geological Survey, Washington, D. C.*

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## REPORT OF PROF. W. M. FONTAINE.

University of Virginia, Va.,
*July* 1, 1888.

Sir: I have to report the following work done during the past year:

Last summer I visited the State of Alabama and examined certain strata known as the Tuscaloosa formation. The examination was made with a view of determining the amount and character of the plant fossils existing in this formation. The plants were found to exist in great numbers at several horizons and at widely separated localities. Their preservation is such as to permit the determination of most of them.

A small number of fossils from different localities and horizons were collected, but they can be considered only as indicating the character of the flora. A much more extensive search is required to gain a collection that can be regarded as exhaustive.

Subsequent study showed that the plants in question form a flora not hitherto studied, which is rich and abounding in dicotyledons. Dicotyledons predominate by far, and the evidence, so far as it goes, indicates for the beds an age not far from that of the upper member of the Potomac formation. This group of beds deserves examination for invertebrate and vertebrate fossils. These have not yet been found, but the character of much of the material is highly favorable for their preservation.

Besides the above, I have been engaged in the study of the fossil plants obtained in Alabama, and also in the completion of my report

on the geology of the Potomac formation in Virginia. This report was submitted to you in the fall.

I have also been occupied in the examination of a small collection of fossil plants from the copper mines of New Mexico, and in selecting, labeling, and wrapping type specimens of plants from the Potomac formation of Maryland and Virginia. This work is now being done with the purpose of transmitting the fossils to the National Museum. The amount of material is very large and the work very tedious.

Respectfully submitted,

WM. M. FONTAINE.

Hon. J. W. POWELL,

*Director U. S. Geological Survey, Washington, D. C.*

## REPORT OF PROF. SAMUEL H. SCUDDER.

DIVISION OF FOSSIL INSECTS,
*Cambridge, Mass., July* 1, 1888.

SIR: During the year just ended the Tertiary insects of North America, and particularly of Florissant, Colorado, have been the basis of the greater part of the work in my division. The Clavicorn series has formed the principal object of study and has proved an exceptionally difficult group. Besides this, much attention has been given to some new accessions to the Carboniferous insect fauna of the country, including a few from a new locality in the coal-field of Rhode Island. Removal to a new laboratory interfered for a brief time with continuous work, but this has already been more than made good by the greater advantages it offers. A considerable amount of material on Coleoptera has been prepared for publication at some future time, and a beginning made on the preparation for the press of a complete index to the described fossil insects of the world, which includes many thousand cards and perhaps three times as many references, arranged in a mixed alphabetical and systematic series.

Much time has been given to the careful selection of material for drawing and to the close revision of the drawings at each stage of their preparation by Mr. J. H. Blake. These have been mostly confined to Tertiary Hymenoptera, of which more than one hundred drawings have now been completed, while a beginning has been made on Carboniferous Blattariæ, of which half a dozen figures have been finished.

Respectfully submitted,

SAM. H. SCUDDER,
*Paleontologist in Charge.*

Hon. J. W. POWELL,

*Director U. S. Geological Survey, Washington, D. C.*

## REPORT OF DR. DAVID T. DAY.

DIVISION OF MINING STATISTICS AND TECHNOLOGY,
*Washington, D. C., July* 1, 1888.

SIR: I have the honor to present the following administrative report of the work in the Division of Mining Statistics and Technology during the official year 1887–'88:

During the first month of the year the revision of the manuscript for the volume "Mineral Resources of the United States, 1886," was completed. On August 15 this report was in the hands of the Public Printer, and on December 22 the volume was published and ready for distribution. During the month of March, 1888, a chart showing the mineral products of the United States during 1886 was compiled and 3,000 copies were distributed.

For several months prior to the close of the fiscal year the work on the statistical report for the calendar year 1887 was in course of preparation. The following is a summary of the metallic and non-metallic mineral products, showing an aggregate value of $542,331,796 for the year. This is the largest total ever reached by the mineral industries of any country. It is nearly seventy-seven million dollars more than the product of the United States in 1886, and considerably more than one hundred million dollars in excess of the year 1885. Of many items which have contributed to this result it will be noted that all the metals increased in quantity except gold and the minor metal, nickel, and nearly all increased in price. The significance of this is seen in the increased production of the fuels necessary for reducing these metals and preparing them for use. All of these fuels, including natural gas, show a marked gain. The increased value of building stone is principally due to a more careful canvass of this industry than has been possible in previous years.

*Iron.*—The principal statistics for 1887 were: Domestic iron ore consumed, about 11,300,000 long tons; value at mines, $33,900,000, an increase over 1886 of 1,300,000 tons in quantity and $5,900,000 in value. Imported iron ore consumed, 1,194,301 long tons; total iron consumed in 1887, about 12,494,301 long tons, or 1,454,868 tons more than in 1886. Pig iron made, 6,417,148 long tons; value at furnace, $121,925,800. This is an increase over 1886 of 733,819 tons in quantity and $26,730,040 in value. Steel of all kinds produced, 3,339,071 long tons, an increase of 776,569 tons over 1886; value at works, $103,811,000. Total spot value of all iron and steel in the first stage of manufacture, excluding all duplications, $171,103,000, an increase of $28,603,000 as compared with 1886. Limestone used as flux in the manufacture of pig iron in 1887, about 5,377,000 long tons; value at quarry, about $3,226,200.

*Gold and Silver.*—The total value of gold produced in 1887 was $33,100,000, a decrease of $1,900,000 from 1886. Silver increased from $51,000,000 in 1886 to $53.441,300 (coining value) in 1887.

*Copper.*—Total production 185,227,331 pounds, of which 3,750,000 pounds were made from imported pyrites. The total value was $21,115,916, at an average of 11.4 cents per pound. The estimated total consumption of copper in the United States increased by about 14 per cent.

*Lead.*—The production of lead was 160,700 short tons, valued at $14,463,000, at $90 per short ton. The heavy increase of "desilverized" lead from 114,829 short tons in 1886 to 135,552 in 1887, was probably due to the importation of Mexican lead-silver ores. The large product of non-argentiferous lead, 25,148 short tons, is due chiefly to the development of the Saint Joe district in southeastern Missouri. The production of white lead and the several oxides from pig lead increased to a total of about 75,000 short tons.

*Zinc.*—The producers' returns show an increase from 42,641 short tons in 1886 to 50,340 in 1887. The price increased to 4¾ cents per pound, making the total value in 1887, $4,782,300. The production of zinc oxide was practically steady at 18,000 short tons, valued at $1,440,000.

*Quicksilver.*—Production and value increased from 29,981 flasks, valued at $1,060,000, to 33,825 flasks, valued at $1,429,000. Except 65 flasks from Oregon, the total supply came from California. The price in 1887 varied from $36.50 to $48 per flask in San Francisco.

*Nickel.*—The supply includes 183,115 pounds of metallic nickel, valued at $117,200, 10,846 pounds of metallic nickel contained in matte, and 11,595 pounds contained in nickel ammonium sulphate. Total value, $133,200.

*Cobalt oxide.*—The product includes 5,769 pounds of cobalt oxide for potters' use, and 12,571 pounds of oxide in matte exported to Europe. Total value $18,774.

*Chromium.*—Shipments from California increased to 3,000 long tons on account of better freight facilities by rail to the eastern States. The total value in San Francisco was $40,000.

*Manganese.*—The total production of manganese ore in the year ending December 31, 1887, was 34,524 tons, valued at $333,844. The production of manganiferous iron ore was 211,751 tons, valued at about $600,000. The production of argentiferous manganese ores was 60,000 tons, valued, chiefly for the silver, at about $600,000.

*Antimony.*—The production, all in California, was 75 tons, valued at $15,500. This is an increase from 35 tons in 1886, valued at $7,000.

*Aluminum.*—The production of aluminum bronze containing 10 per cent. aluminum increased to 144,764 pounds in 1887, valued at $57,905. Other alloys, principally of iron and aluminum, amounted

to 42,617 pounds, worth $17,000. Pure aluminum contained in these alloys was 18,000 pounds, valued at $59,000.

*Platinum.*—Considerable search by dealers produced 448 ounces of crude platinum, valued at $1,838. Part of this came from British Columbia.

FUELS.

*Coal.*—The total production of all kinds of commercial coal in 1887 was 124,015,255 short tons (increase over 1886, 16,283,046 tons), valued at the mines at $173,530,996 (increase, $26,333,046). This may be divided into Pennsylvania anthracite, 39,506,255 short tons (increase, 2,809,780 short tons), or 35,273,442 long tons (increase, 2,508,732 long tons), valued at $79,365,244 (increase, $7,807,118); all other coals, including bituminous, brown coal, lignite, small lots of anthracite produced in Colorado and Arkansas, and 6,000 tons of graphitic coal mined in Rhode Island, amounting in the aggregate to 84,509,000 short tons (increase, 13,523,266 tons), valued at $98,004,656 (increase, $19,523,600).

The colliery consumption at the individual mines varies from nothing to 8 per cent. of the total output of the mines, being greatest at special Pennsylvania anthracite mines and lowest at those bituminous mines where the coal bed lies nearly horizontal and where no steam power or ventilating furnaces are used. The averages for the different States vary from $2\frac{1}{10}$ to $6\frac{1}{7}$ per cent., the minimum average being in the Pennsylvania bituminous and the maximum average being in the Pennsylvania anthracite region.

The total output of the mines, including colliery consumption, was, Pennsylvania anthracite, 37,578,747 long tons (increase over 1886, 2,725,670 long tons), or 42,088,197 short tons (increase, 3,052,751 short tons); all other coals, 87,887,360 short tons (increase, 14,179,403 tons), making the total output of all coals from mines in the United States, exclusive of slack coal thrown on the dumps, 129,975,557 short tons (increase, 17,232,154 tons), valued as follows: Anthracite, $84,552,181 (increase, $8,433,061); bituminous, $98,004,656 (increase, $19,523,600); total value, $182,556,837 (increase, $27,956,661). The above figures show a notable increase in 1887 over 1886 in the aggregate output and value of both anthracite and bituminous coal.

*Coke.*—The total production of coke in the United States for the year ending December 31, 1887, was 7,857,487 short tons, valued at $15,723,574. This is the greatest product ever reached in the United States, being 1,022,419 tons greater than in 1886.

*Petroleum.*—Total production 28,249,597 barrels of 42 gallons each. The total value at an average of $66\frac{3}{4}$ cents was $18,856,606. The increase over 1886 was very slight, only 139,482 barrels. There was a decrease of $4\frac{1}{2}$ cents per barrel in the average price.

*Natural gas.*—The production of natural gas in the United States in 1887 was equivalent to 9,867,000 short tons of coal displaced. This, at an average value of $1.50 a ton, would make the value of the coal displaced by natural gas (which is the measure of the value of the gas) $15,838,500. In 1886 the corresponding quantity was 6,353,000 tons, worth $9,847,150.

STRUCTURAL MATERIALS.

*Building stone.*—Direct returns from producers show a total value of $25,000,000. The marked increase, $6,000,000, shows that the statement for 1886 was too small.

*Brick and tile.*—Value $47,000,000. This represents an increase of about 13 per cent. in the production of brick and a decrease in tile, owing to the drought in 1887 in Indiana and Ohio. Prices were slightly lower.

*Lime.*—The production is estimated at 46,750,000 barrels with an average value of 50 cents per barrel.

*Cement.*—The production of cement from natural rock was 6,692,744 barrels, valued at 77½ cents per barrel, making $5,186,877 as the value of the year's product.

ABRASIVE MATERIALS.

*Buhrstones.*—The value of the product is estimated at $200,000.

*Grindstones.*—In Ohio and Michigan 27,400 tons were produced, valued at $224,400.

*Corundum.*—Total production from North Carolina and Georgia 600 short tons with a spot value of $108,000.

*Novaculite.*—Production 1,200,000 pounds, valued in the rough state at $16,000.

*Infusorial earth.*—Maryland produced 3,000 tons, worth $15,000. A small quantity was produced in Nevada and New Mexico.

MISCELLANEOUS.

*Precious stones.*—The value of American gems in the rough state amounted to $88,600, besides gold quartz for specimens and gems, valued at $75,000.

*Phosphate rock.*—South Carolina phosphate rock aggregated 480,558 long tons, valued at $1,836,818, an increase of 50,009 tons in quantity, but a decrease of $36,118 in the value, due to greater competition which reduced the price to $3.75 a ton for land and $4 for river rock.

*Marls.*—In New Jersey the production is estimated at 600,000 tons worth about $300,000. While the New Jersey marl is yielding slowly to commercial fertilizers, the Virginia marls, as well as those in North and South Carolina, Georgia, Mississippi, and Florida, are finding increased local use.

*Salt.*—Production in 1887, 8,003,962 barrels (of 280 pounds), value $4,093,846. The annual production has increased each year since 1883, but the total value has declined, being less in 1887 than in 1884, although only 6,514,937 barrels were made in the latter year.

*Bromine.*—Stocks accumulated in 1886 and reduced the output of 1887 to 199,087 pounds, valued at $61,717. The price was held at 31 cents per pound.

*Borax.*—Production, 11,000,000 pounds, all from California and Nevada. Total value, $550,000, at 5 cents per pound for the average grade. The price was rising at the close of 1887.

*Sulphur.*—Production, about 3,000 tons from Utah, worth $100,000. Litigation checked the use of an increased plant. The imports of Sicilian sulphur, with small shipments from Japan, were 96,882 long tons, valued at $1,688,360.

*Pyrites.*—Production, 52,500 long tons, valued at $210,000 at $4 per ton at the mines.

*Barytes.*—The production increased to 15,000 long tons of crude barytes, valued at $75,000 at the mines.

*Gypsum.*—The condition of the industry is practically unchanged. The estimated total product was 95,000 short tons of crude gypsum, valued at $425,000. In addition, 162,154 long tons of crude gypsum were imported, chiefly from Nova Scotia.

*Mica.*—The production increased to 70,500 pounds, valued at $142,250. The increase was chiefly in North Carolina. New Hampshire, Massachusetts, and Virginia also produced mica. No shipments were reported from the Black Hills or New Mexico. The use of mica waste is increasing; 2,000 tons, worth $15,000, were ground in 1887.

*Feldspar.*—The amount consumed, principally by potters, was 10,200 long tons, valued at $56,100 before grinding. This includes freight to the principal markets, Trenton or New York. The consumption in 1886 was about 5,000 tons less than the production returned by quarrymen.

*Flint.*—For pottery 19,800 tons were used. Including the use for sandpaper and in glass manufacture, the total consumption was about 32,000 tons, worth, unground, $185,000.

*Potter's clay.*—The consumption of kaolin and ball clay by potters aggregated 28,000 tons, valued at $290,000. In addition, the potters used 15,000 tons of fire-clay, worth $50,000.

*Asbestus.*—The total product hardly exceeded 150 tons, worth $4,500. In addition, several hundred tons of fibrous actinolite were used for weighting paper.

*Mineral paints.*—Including ocher, metallic paints, and small quantities of umber and sienna, the production amounted to 20,000 long tons, selling for $310,000 at the mines.

*Graphite.*—The production at Ticonderoga is reported as unchanged. Small lots, ranging from graphitic clay to pure graphite, were produced in North Carolina. Total production, 416,000 pounds, worth $34,000. This does not include 500 tons of impure graphite mined in Rhode Island for foundry facings, etc.

*Fluorspar.*—The production remained constant at 5,000 tons in Indiana. The total value was $20,000.

*Mineral waters.*—The production which was sold amounted to 8,259,609 gallons, worth $1,261,473.

*Metallic products of the United States in* 1887.

| | Quantity. | Value. |
|---|---|---|
| Pig iron, spot value ........long tons.. | 6,417,148 | $121,925,800 |
| Silver, coining value........troy ounces.. | 41,269,240 | 53,441,300 |
| Gold, coining value........do.... | 1,596,500 | 33,100,000 |
| Copper, value at New York City........pounds.. | 185,227,331 | 21,115,916 |
| Lead, value at New York City ........short tons.. | 160,700 | 14,463,000 |
| Zinc, value at New York City........do.... | 50,340 | 4,782,300 |
| Quicksilver, value at San Francisco........flasks.. | 33,825 | 1,429,000 |
| Nickel, value at Philadelphia ........pounds.. | 205,556 | 133,200 |
| Aluminum contained in alloys ........do... | 18,000 | 59,000 |
| Antimony, value at San Francisco........short tons.. | 75 | 15,500 |
| Platinum, value (crude) at New York City........troy ounces.. | 448 | 1,838 |
| Total ........ | ........ | 250,466,854 |

*Non-metallic mineral products of the United States in* 1887 (*spot values*).

| | Quantity. | Value. |
|---|---|---|
| Bituminous coal ........long tons.. | 78,470,857 | $98,004,656 |
| Pennsylvania anthracite........do.... | 37,578,747 | 84,552,181 |
| Building stone........ | ........ | 25,000,000 |
| Lime ........barrels.. | 46,750,000 | 23,375,000 |
| Petroleum ........do.... | 28,249,597 | 18,856,606 |
| Natural gas........ | ........ | 15,838,500 |
| Cement ........barrels.. | 6,692,744 | 5,186,877 |
| Salt ........do.... | 8,003 962 | 4,093,846 |
| Limestone for iron flux ........long tons.. | 5,377,000 | 3,226,200 |
| South Carolina phosphate rock ........do.... | 480,558 | 1,836,818 |
| Zinc-white ........short tons. | 18,000 | 1,440,000 |
| Mineral waters ........gallons sold.. | 8,259,609 | 1,261,473 |
| Borax ........pounds.. | 11,000,000 | 550,000 |
| Gypsum........short tons.. | 95,000 | 425,000 |
| Manganese ore........long tons.. | 34,524 | 333,844 |
| Mineral paint ........do.... | 20,000 | 310,000 |
| New Jersey marls........short tons.. | 600,000 | 300,000 |
| Pyrites........long tons.. | 52,500 | 210,000 |
| Flint ........do.... | 32,000 | 185,000 |
| Mica........pounds.. | 70,500 | 142,250 |
| Corundum ........short tons.. | 600 | 108,000 |
| Sulphur ........do.... | 3,000 | 100,000 |

*Non-metallic mineral products of the United States in* 1887 (*spot values*)—Continued.

| | Quantity. | Value. |
|---|---|---|
| Precious stones | .......... | $88,600 |
| Crude barytes ... long tons.. | 15,000 | 75,000 |
| Gold-quartz souvenirs, jewelry, etc | .......... | 75,000 |
| Bromine ... pounds.. | 199,087 | 61,717 |
| Feldspar ... long tons.. | 10,200 | 56,100 |
| Chrome iron ore ... do.... | 3,000 | 40,000 |
| Graphite ... pounds.. | 416,000 | 34,000 |
| Fluorspar ... short tons.. | 5,000 | 20,000 |
| Slate ground as pigment ... long tons.. | 2,000 | 20,000 |
| Cobalt oxide ... pounds.. | 18,340 | 18,774 |
| Novaculite ... do.... | 1,200,000 | 16,000 |
| Asphaltum ... short tons.. | 4,000 | 16,000 |
| Asbestus ... do.... | 150 | 4,500 |
| Rutile ... pounds.. | 1,000 | 3,000 |
| Total | .......... | 285,864,942 |

*Résumé of the values of the metallic and non-metallic mineral substances produced in the United States in* 1887.

| | |
|---|---|
| Metals | $250,466,854 |
| Mineral substances named in the foregoing table | 285,864,942 |
| | 536,331,796 |
| Estimated value of mineral products unspecified | 6,000,000 |
| Grand total | 542,331,796 |

During the year considerable time has been devoted to information regarding the occurrence and utilization of the mineral products, in reply to numerous inquiries.

In conducting the work of the division Mr. William A. Raborg and Mr. Jefferson Middleton, and latterly Dr. C. W. Hayes, who constituted the office staff, deserve especial mention for the valuable aid they have rendered.

Very respectfully, your obedient servant,

David T. Day,
*Geologist in Charge.*

Maj. J. W. Powell,
*Director U. S. Geological Survey, Washington, D. C.*

## REPORT OF PROF. F. W. CLARKE.

DIVISION OF CHEMISTRY AND PHYSICS,
*Washington, D. C., July* 1, 1888.

SIR: I have the honor to submit herewith a report of the work done in the Division of Chemistry and Physics during the fiscal year ending June 30, 1888.

The personnel of the division, which on the first of last July consisted of Dr. Hillebrand, Dr. Chatard, Dr. Riggs, Mr. Whitfield, and myself, in the chemical laboratory, and Drs. Barus and Hallock in the physical laboratory, has undergone some changes during the year. The division has suffered by the resignation of Dr. Robert B. Riggs, who was called to the chair of chemistry at Trinity College, Hartford, Conn. Prior to his resignation, which took place last September, he prepared for publication the results of his investigation on the chemical composition of tourmaline, which was commenced in the winter of 1885–'86, and which was carried on in connection with his daily routine work. His paper represents probably the most thorough investigation of this difficult problem extant, and is a valuable addition to the literature of chemical mineralogy.

About the first of February, when the branch office of the Survey at Denver was abolished, Mr. L. G. Eakins, of that division, was transferred to this laboratory, and has since been engaged in various investigations of scientific interest; notably the analysis and study of a clay, "xanthitane," which contains titanium in the place of silica.

Last August Mr. Charles Catlett, of the office force, was detailed to this division, to act as a laboratory assistant and to do such clerical work as the division calls for. He has since that time been engaged in making chemical analyses of various kinds and of more or less interest, and has handled all the assays for gold and silver.

Dr. George Latimer was temporarily detailed to this office in February; since which time he has been employed on the mineral collection.

The force in this division consists at present of six chemists, two physicists, one clerk, and two laborers.

The chemical work of the year has necessarily been of a very varied nature, and has largely been expended on material furnished by the field geologists, but some interesting original researches have been brought to a successful termination. While of course the number of analyses is not a fair criterion of the amount of work accomplished, it may be well to notice that the total number of assays and analyses reported for the past fiscal year was 426, against 335 for the year ending June 30, 1887. Quite a number of analyses have from time to time been made as an accommodation to the other bu-

reaus of the Government; for instance, the Government Printing Office, the Bureau of Engraving and Printing, the Supervising Architect, etc., and hardly a day passes that minerals for identification do not reach us through one channel or another.

During the year my personal laboratory work has been necessarily somewhat hampered by administrative duties, and I was absent a portion of last summer in England. An interesting series of analyses, undertaken with a view to ascertaining the genesis of the nickel silicates of Oregon, was completed recently. These ores have essentially the same characteristics as those from New Caledonia and North Carolina, and my investigation was a complete confirmation of the idea that the nickel of the greater silicate deposits is derived from the alteration of nickeliferous olivine. I was greatly assisted in my researches in this direction by the microscopic examination made for me by Mr. Diller. I have also, in connection with Mr. G. P. Merrill, of the National Museum, investigated the chemical nature of jaedeite and nephrite, of which the National Museum collection furnished abundant material for analysis and microscopic study. Our analyses cover specimens from Alaska, Mexico, Costa Rica, New Zealand, and the Swiss lake dwellings, and by this extended comparison enable the character and composition of the minerals to be very thoroughly understood.

Dr. Hillebrand has brought to a successful completion the study of certain rare copper minerals from Utah, most of which were new to this country, and one (mixite) had previously been known in but one other locality in the world. Dr. Hillebrand finished last fall the analysis of an extensive series of the volcanic eruptive rocks from Lassen Peak, furnished by Mr. J. S. Diller, and he is now continuing an investigation on the uraninites of North America, which was begun some time since. Like all of the chemists, his time has been largely consumed in the analysis of miscellaneous material furnished by the various geologists through the central office.

The rapid increase in the meteorite collection of the Museum in the last few years, and the kindness of various owners of other meteorites, has placed a large amount of this interesting material at our disposal for analysis and study, and a number of specimens have been examined during the past twelve months. Some of these analyses are very elaborate and exhaustive, and the results obtained are exceedingly valuable additions to the literature of the subject. Mr. Whitfield's familiarity with work of this character has enabled him to handle successfully a number of specimens of this class, representing at least six new and undescribed falls. He has also analyzed a large series of rocks, waters, sediments, etc., from the Yellowstone National Park, furnished by Mr. Hague.

The work commenced by Dr. Chatard about two years ago, on the natural alkali deposits of the West, is being pushed toward comple-

tion, and tends to throw much light upon the rather complicated problem of their origin. During three months of last summer he was in the field, mostly at Owen's Lake, examining the economic working of the deposits and collecting material for analysis and study, and this has occupied his attention during the past winter.

In the physical laboratory much valuable work has been finished and the results submitted for publication.

Dr. Barus has prepared an extensive memoir on the subject of the measurement of high temperatures, and since the completion of this he has been investigating a new development or extension of air thermometry. His paper on the latter subject is at present being prepared for the press.

The larger portion of Dr. Hallock's time has been consumed in the preparatory work on coefficients of expansion, and unfortunately much time has been unavoidably occupied in the mechanical preparation of apparatus and fixtures. He has prepared during the year a paper on the flow of solids, which is very interesting from a geological stand-point, and has made some startling discoveries in regard to the formation of fusible alloys at low temperatures. His results, briefly generalized, may be stated thus: All fusible alloys may be formed from their solid components at temperatures slightly, if any, in excess of the melting-point of the product. Thus Wood's alloy, fusing at 66° C., is formed from its constituents at temperatures below 100°; although no one of the metals entering into it fuses below 230° separately.

Very respectfully, yours,

F. W. CLARKE,
*Chief Chemist.*

Hon. J. W. POWELL,
*Director U. S. Geological Survey, Washington, D. C.*

## REPORT OF MR. W. H. HOLMES.

DIVISION OF ILLUSTRATIONS,
*Washington, D. C., July* 1, 1888.

SIR: During the last year the work of this division has increased to a very considerable extent, but has been carried on without important change in character of subject-matter or in methods of procedure. Slight changes have been made in the personnel of the force. One draughtsman, Mr. H. H. Birney, has resigned, and two draughtsmen, Mr. H. M. Reeve and Mr. H. H. Nichols, have been added.

During my somewhat prolonged absence from the office occasioned by field work in the fall, and illness in the spring, the work of the division was ably conducted by Mr. De Lancey W. Gill. Mr. John L. Ridgway has had personal supervision of a large part of

the paleontologic drawing, and has done excellent service in elevating the standard of pen drawing.

Two annual reports, one monograph, and nine bulletins have been transmitted through this office. The illustrations for these may be classed as follows:

Twenty-four plates by chromo-lithography.
Six plates by lithography.
Fifty-nine plates by wood-engraving.
Ninety-four plates by photo-engraving.
Twenty plates by photo-lithography.
One plate by engraving on stone.
Sixty figures by wood-engraving.
One hundred and eighty-one figures by photo-engraving.

This statement does not include maps and charts prepared in other divisions of the Survey.

The following list shows approximately the number and character of the drawings executed since June 30, 1887:

Fossil mollusca, 452 figures.
Fossil vertebrates, 30 plates and 150 figures.
Fossil insects, 115 figures.
Fossil plants, 225 figures.
Mineralogic specimens, 24 figures and plates.
Microscopic sections, 25 figures.
Geologic landscapes, 50 figures and plates.
Sections and diagrams, 405 figures and plates.

I include in this statement drawings made by a number of geologists and their assistants whose work is not directly supervised by me.

The photographic work, in charge of Mr. J. K. Hillers, has been carried on without important change. Two parties were sent into the field. One of these, conducted by Mr. C. C. Jones, secured thirty 11 by 14 inch negatives, and the other conducted by Mr. F. T. Smart, secured one hundred 5 by 8 negatives. The following is a list of the negatives, prints, and transparencies made during the year:

| Negatives. | | Prints. | | Transparencies. | |
|---|---|---|---|---|---|
| Size (in inches). | Number. | Size (in inches). | Number. | Size (in inches). | Number. |
| 28 by 34 | 191 | 28 by 34 | 664 | 28 by 34 | 65 |
| 20 by 24 | 271 | 20 by 24 | 1,962 | 20 by 24 | 15 |
| 14 by 17 | 17 | 14 by 17 | 33 | | |
| 11 by 14 | 117 | 11 by 14 | 1,264 | | |
| 8 by 10 | 789 | 8 by 10 | 1,298 | | |
| 5 by 8 | 119 | 5 by 8 | 379 | | |

Very respectfully, your obedient servant,

W. H. Holmes,
*Geologist in Charge.*

Hon. J. W. Powell,
*Director U. S. Geological Survey, Washington, D. C.*

## REPORT OF MR. C. C. DARWIN.

DIVISION OF LIBRARY AND DOCUMENTS,
*Washington, D. C., July* 1, 1888.

SIR: I have the honor to submit the following statement of work done in this division during the fiscal year ended June 30, 1888:

### LIBRARY.

A new rack, 27.10 by 9.6 feet, has been built during the year, providing 415 additional feet of shelf room, and this has been gained with but little sacrifice of floor space by such an arrangement of three racks as makes them occupy laterally not much more space than was before occupied by two. This added shelf room has permitted the proper shelving of books already in the library, but leaves us, at the commencement of the coming year, to face the great difficulty of properly administering a growing and continually consulted library within a limit that can be further crowded only at the expense of usefulness.

*Contents of the library, June 30, 1888.*

| | | | |
|---|---|---|---|
| **BOOKS.** | | | |
| On hand June 30, 1887: | | | |
| Received by exchange | 14,691 | | |
| Received by purchase | 4,810 | | |
| | | 19,501 | |
| Received during the past year: | | | |
| By exchange | 1,719 | | |
| By purchase | 243 | | |
| | | 1,962 | |
| | | | 21,463 |
| **PAMPHLETS.** | | | |
| On hand June 30, 1887: | | | |
| Received by exchange | 24,650 | | |
| Received by purchase | 1,450 | | |
| | | 26,100 | |
| Received during the past year: | | | |
| By exchange | 3,800 | | |
| By purchase | 200 | | |
| | | 4,000 | |
| | | | 30,100 |
| Total number of books and pamphlets | | | 51,563 |

As in the past, the actual every-day demands of library routine have prevented more than an author-indexing and arrangement of the books and pamphlets received.

The same high average of current circulation as of previous years holds good for this year. Over one thousand books have been issued and returned every month. Two thousand and six volumes have been bound during the year.

*Bibliography.*—The Catalogue of the Literature of North American Geology progresses with as much rapidity as is consistent with accuracy and the constant interruption it suffers from the routine work of the library.

Over twenty thousand titles, however, have been collected, and, as far as possible, the time of one clerk is given to perfecting and verifying these.

By separating from this mass those titles which relate to official research, it will be possible to publish at an early date a bibliography of the literature of official geological exploration in North America.

This of itself would make a voluminous catalogue and be of some service until the general work were ready. Three thousand titles are already complete from a bibliographer's stand-point. The remaining titles are in hand, and this section of the work will be finished as rapidly as circumstances permit.

## PUBLICATIONS.

Monograph XII, Bulletins 40, 41, 42, and 44, and the fourth volume of Mineral Resources have been published during the year. The list of publications of the Survey, corrected to June 30, 1888, is as follows:

### *Annual reports.*

I. First Annual Report of the U. S. Geological Survey, by Clarence King. 1880. 8°. 79 pp. 1 map.—A preliminary report describing plan of organization and publications.

II. Second Annual Report of the U. S. Geological Survey, 1880–'81, by J. W. Powell. 1882. 8°. lv, 588 pp. 61 pl. and 1 map.

III. Third Annual Report of the U. S. Geological Survey, 1881–'82, by J. W. Powell. 1883. 8°. xviii, 564 pp. 67 pl. and maps.

IV. Fourth Annual Report of the U. S. Geological Survey, 1882–'83, by J. W. Powell. 1884. 8°. xxxii, 473 pp. 85 pl. and maps.

V. Fifth Annual Report of the U. S. Geological Survey, 1883–'84, by J. W. Powell. 1885. 8°. xxxvi, 469 pp. 58 pl. and maps.

VI. Sixth Annual Report of the U. S. Geological Survey, 1884–'85, by J. W. Powell. 1885. 8°. xxix, 570 pp. 65 pl. and maps.

### *Monographs.*

II. Tertiary History of the Grand Cañon District, with atlas, by Clarence E. Dutton, Capt. U. S. A. 1882. 4°. xiv, 264 pp. 42 pl. and atlas of 24 sheets folio. Price $10.12.

III. Geology of the Comstock Lode and the Washoe District, with atlas, by George F. Becker. 1882. 4°. xv, 422 pp. 7 pl. and atlas of 21 sheets folio. Price $11.

IV. Comstock Mining and Miners, by Eliot Lord. 1883. 4°. xiv, 451 pp. 3 pl. Price $1.50.

V. Copper-bearing Rocks of Lake Superior, by Roland D. Irving. 1883. 4°. xvi, 464 pp. 15 l. 29 pl. Price $1.25.

VI. Contributions to the Knowledge of the Older Mesozoic Flora of Virginia, by Wm. M. Fontaine. 1883. 4°. xi, 144 pp. 54 l. 54 pl. Price $1.05.

VII. Silver-Lead Deposits of Eureka, Nevada, by Joseph S. Curtis. 1884. 4°. xiii, 200 pp. 16 pl. Price $1.20.

VIII. Paleontology of the Eureka District, by Charles D. Walcott. 1884. 4°. xiii, 298 pp. 24 l. 24 pl. Price $1.10.

IX. Brachiopoda and Lamellibranchiata of the Raritan Clays and Greensand Marls of New Jersey, by Robert P. Whitfield. 1885. 4°. xx, 338 pp. 35 pl. Price $1.15.

X. Dinocerata : A Monograph of an Extinct Order of Gigantic Mammals, by Othniel Charles Marsh. 1885. 4°. xviii, 243 pp. 56 l. 56 pl. Price $2.70.

XI. Geological History of Lake Lahontan, a Quaternary Lake of Northwestern Nevada, by Israel Cook Russell. 1885. 4°. xiv, 288 pp. 46 pl. Price $1.75.

XII. Geology and Mining Industry of Leadville, Colorado, with atlas, by S. F. Emmons. 1886. 4°. xxix, 770 pp. 45 pl. and atlas of 35 sheets folio. Price $8.40.

*Bulletins.*

1. On Hypersthene-Andesite and on Triclinic Pyroxene in Augitic Rocks, by Whitman Cross, with a Geological Sketch of Buffalo Peaks, Colorado, by S. F. Emmons. 1883. 8°. 42 pp. 2 pl. Price 10 cents.

2. Gold and Silver Conversion Tables, giving the coining values of troy ounces of fine metals, etc., by Albert Williams, jr. 1883. 8°. 8 pp. Price 5 cents.

3. On the Fossil Faunas of the Upper Devonian along the Meridian of 76° 30′, from Tompkins County, N. Y., to Bradford County, Pa., by Henry S. Williams. 1884. 8°. 36 pp. Price 5 cents.

4. On Mesozoic Fossils, by Charles A. White. 1884. 8°. 36 pp. 9 pl. Price 5 cents.

5. A Dictionary of Altitudes in the United States, compiled by Henry Gannett. 1884. 8°. 325 pp. Price 20 cents.

6. Elevations in the Dominion of Canada, by J. W. Spencer. 1884. 8°. 43 pp. Price 5 cents.

7. Mapoteca Geologica Americana: A Catalogue of Geological Maps of America (North and South), 1752–1881, by Jules Marcou and John Belknap Marcou. 1884. 8° 184 pp. Price 10 cents.

8. On Secondary Enlargements of Mineral Fragments in Certain Rocks, by R. D. Irving and C. R. Van Hise. 1885. 8°. 56 pp. 6 pl. Price 10 cents.

9. Report of Work Done in the Washington Laboratory during the Fiscal Year 1883–'84. F. W. Clarke, chief chemist; T. M. Chatard, assistant. 1884. 8°. 40 pp. Price 5 cents.

10. On the Cambrian Faunas of North America. Preliminary Studies, by Charles D. Walcott. 1884. 8°. 74 pp. Price, 5 cents.

11. On the Quaternary and Recent Mollusca of the Great Basin, with Descriptions of New Forms, by R. Ellsworth Call; Introduced by a Sketch of the Quaternary Lakes of the Great Basin, by G. K. Gilbert. 1884. 8°. 66 pp. 6 pl. Price 5 cents.

12. A Crystallographic Study of the Thinolite of Lake Lahontan, by Edward S. Dana. 1884. 8°. 34 pp. 3 pl. Price 5 cents.

13. Boundaries of the United States and of the several States and Territories, by Henry Gannett. 1885. 8°. 135 pp. Price 10 cents.

14. The Electrical and Magnetic Properties of the Iron-Carburets, by Carl Barus and Vincent Strouhal. 1885. 8°. 238 pp. Price 15 cents.

15. On the Mesozoic and Cenozoic Paleontology of California, by Charles A. White. 1885. 8°. 33 pp. Price 5 cents.

16. On the Higher Devonian Faunas of Ontario County, N. Y., by John M. Clarke. 1885. 8°. 86 pp. 3 pl. Price 5 cents.

17. On the Development of Crystallization in the Igneous Rocks of Washoe, Nevada, by Arnold Hague and Joseph P. Iddings. 1885. 8°. 44 pp. Price 5 cents.

18. On Marine Eocene, Fresh-Water Miocene, and other Fossil Mollusca of Western North America, by Charles A. White. 1885. 8°. 26 pp. 3 pl. Price 5 cents.

19. Notes on the Stratigraphy of California, by George F. Becker, 1885. 8°. 28 pp. Price 5 cents.

20. Contributions to the Mineralogy of the Rocky Mountains, by Whitman Cross and W. F. Hillebrand. 1885. 8°. 114 pp. 1 pl. Price 10 cents.

21. The Lignites of the Great Sioux Reservation, by Bailey Willis. 1885. 8°. 16 pp. 5 pl. Price 5 cents.

22. On New Cretaceous Fossils from California, by Charles A. White. 1882. 8°. 25 pp. 5 pl. Price 5 cents.

23. Observations on the Junction between the Eastern Sandstone and the Keweenaw Series on Keweenaw Point, Lake Superior, by R. D. Irving and T. C. Chamberlin. 1885. 8°. 124 pp. 17 pl. Price 15 cents.

24. List of Marine Mollusca, comprising the Quaternary Fossils and recent forms from American Localities between Cape Hatteras and Cape Roque, including the Bermudas, by William H. Dall. 1885. 8°. 336 pp. Price 25 cents.

25. The Present Technical Condition of the Steel Industry of the United States, by Phineas Barnes. 1885. 8°. 85 pp. Price 10 cents.

26. Copper Smelting, by Henry M. Howe. 1885. 8°. 107 pp. Price 10 cents.

27. Report of Work Done in the Division of Chemistry and Physics, mainly during the Fiscal Year 1884–'85. 1886. 8°. 80 pp. Price 10 cents.

28. The Gabbros and Associated Hornblende Rocks occurring in the neighborhood of Baltimore, Md., by George H. Williams. 1886. 8°. 78 pp. 4 pl. Price 10 cents.

29. On the Fresh-Water Invertebrates of the North American Jurassic, by Charles A. White. 1886. 8°. 41 pp. 4 pl. Price 5 cents.

30. Second Contribution to the Studies on the Cambrian Faunas of North America, by Charles D. Walcott. 1886. 8°. 369 pp. Price 25 cents.

31. A Systematic Review of our Present Knowledge of Fossil Insects, including Myriapods and Arachnids, by Samuel H. Scudder. 1886. 8°. 128 pp. Price 15 cents.

32. Mineral Springs of the United States, by Albert C. Peale. 1886. 8°. 235 pp. Price 20 cents.

33. Notes on the Geology of Northern California, by Joseph S. Diller. 1886. 8°. 23 pp. Price 5 cents.

34. On the Relation of the Laramie Molluscan Fauna to that of the succeeding Fresh-Water Eocene and Other Groups, by Charles A. White. 1886. 8°. 54 pp. 5 pl. Price 10 cents.

35. The Physical Properties of the Iron-Carburets, by Carl Barus and Vincent Strouhal. 1886. 8°. 62 pp. Price 10 cents.

36. Subsidence of Fine Solid Particles in Liquids, by Carl Barus. 1887. 8°. 58 pp. Price 10 cents.

37. Types of the Laramie Flora, by Lester F. Ward. 1887. 8°. 354 pp. 57 pl. Price 25 cents.

38. Peridotite of Elliott County, Kentucky, by Joseph S. Diller. 1887. 8°. 31 pp. 1 pl. Price 5 cents.

38. The Upper Beaches and Deltas of the Glacial Lake Agassiz, by Warren Upham. 1887. 8°. 84 pp. 1 pl. Price 10 cents.

40. Changes in River Courses in Washington Territory due to Glaciation, by Bailey Willis. 1887. 8°. 10 pp. 4 pl. Price 5 cents.

41. Fossil Faunas of the Upper Devonian—the Genesee Section, New York, by Henry S. Williams. 1887. 8°. 121 pp. 4 pl. Price 15 cents.

42. Report of Work Done in the Division of Chemistry and Physics, mainly dur-

ing the Fiscal Year 1885-'86. F. W. Clarke, chief chemist. 1887. 8°. 152 pp. 1 pl. Price 15 cents.

44. Bibliography of North American Geology for 1886, by Nelson H. Darton. 1887. 8°. 35 pp. Price 5 cents.

*Statistical papers.*

Mineral Resources of the United States [1882], by Albert Williams, jr. 1883. 8°. xvii, 813 pp. Price 50 cents.

Mineral Resources of the United States, 1883 and 1884, by Albert Williams, jr. 1885. 8°. xiv, 1016 pp. Price 60 cents.

Mineral Resources of the United States, 1885. Division of Mining Statistics and Technology. 1886. 8°. vii, 576 pp. Price 40 cents.

Mineral Resources of the United States, 1886, by David T. Day. 1887. 8°. viii, 813 pp. Price 50 cents.

*Exchange.*—Five thousand five hundred and nineteen books and pamphlets have been received during the year through the operations of exchange; the Sixth Annual Report has been sent to the whole exchange list; Bulletins 34 to 39 and the volume of Mineral Resources for 1886 have been distributed to all entitled to complete exchange; and a partial distribution has been made of Monograph XII, the text being furnished to all addresses in the United States, and the atlas to a few to whom it was desirable it should be speedily supplied.

The distribution during the year is detailed in the following table:

| | | | |
|---|---|---|---|
| Sixth Annual Report | 1,453 | Bulletin 39 | 699 |
| Bulletin 34 | 699 | Monograph XII (text) | 252 |
| Bulletin 35 | 699 | Monograph XII (atlas) | 68 |
| Bul'etin 36 | 699 | Mineral Resources, 1886 | 701 |
| Bulletin 37 | 699 | | |
| Bulletin 38 | 699 | Total | 6,668 |

*Sale.*—The growth of interest in the publications of the Survey is shown by the following statement of total amount of sales for each year from the beginning of such sales:

| | | | |
|---|---|---|---|
| 1883 | $335.26 | 1885-'86 | $767.67 |
| 1883-'84 | 611.70 | 1886-'87 | 925.99 |
| 1884-'85 | 340.32 | 1887-'88 | 1,692,25 |

The following table exhibits in detail the sale account for 1887-'88:

*Sale of publications.*

| Title of work. | Price of work. | Third quarter, 1887. | | Fourth quarter, 1887. | | First quarter, 1888. | | Second quarter, 1888. | | Whole fiscal year. | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Monograph II | $10.12 | .... | ....... | 1 | $10.12 | 1 | $10.12 | 3 | $30.36 | 5 | $50.60 |
| Monograph III | 11.00 | .... | ....... | 3 | 33.00 | 1 | 11.00 | 2 | 22.00 | 6 | 66.00 |
| Monograph IV | 1.50 | 1 | $1.50 | 3 | 4.50 | 4 | 6.00 | 5 | 7.50 | 13 | 19.50 |
| Monograph V | 1.85 | 3 | 5.55 | 3 | 5.55 | 6 | 11.10 | 8 | 14.80 | 20 | 37.00 |
| Monograph VI | 1.05 | 1 | 1.05 | ... | ....... | 2 | 2.10 | 1 | 1.05 | 4 | 4.20 |
| Monograph VII | 1.20 | 1 | 1.20 | 4 | 4.80 | 4 | 4.80 | 6 | 7.20 | 15 | 18.00 |
| Monograph VIII | 1.10 | 2 | 2.20 | 1 | 1.10 | 5 | 5.50 | 3 | 3.30 | 11 | 12.10 |
| Monograph IX | 1.15 | 2 | 2.30 | .... | ...... | 5 | 5.75 | 3 | 3.45 | 10 | 11.50 |
| Monograph X | 2.70 | ... | ....... | 4 | 10.80 | 6 | 16.20 | 3 | 8.10 | 13 | 35.10 |

*Sale of publications*—Continued.

| Title of work. | Price of work. | Third quarter, 1887. | | Fourth quarter, 1887. | | First quarter, 1888. | | Second quarter, 1888. | | Whole fiscal year. | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Monograph XI | $1.75 | 1 | $1.75 | 7 | $12.25 | 6 | $10.50 | 3 | $5.25 | 17 | $29.75 |
| Monograph XII | 8.40 | 1 | 8.40 | 38 | 319.20 | 27 | 226.80 | 13 | 109.20 | 79 | 663.60 |
| Bulletin 1 | .10 | 2 | .20 | 7 | .70 | 12 | 1.20 | 6 | .60 | 27 | 2.70 |
| Bulletin 2 | .05 | 5 | .25 | 8 | .40 | 9 | .45 | 9 | .45 | 31 | 1.55 |
| Bulletin 3 | .05 | 8 | .40 | 7 | .35 | 12 | .60 | 7 | .35 | 34 | 1.70 |
| Bulletin 4 | .05 | 8 | .40 | 8 | .40 | 12 | .60 | 5 | .25 | 33 | 1.65 |
| Bulletin 5 | .20 | 12 | 2.40 | 24 | 4.80 | 31 | 6.20 | 27 | 5.40 | 94 | 18.80 |
| Bulletin 6 | .05 | 5 | .25 | 11 | .55 | 12 | .60 | 11 | .55 | 39 | 1.95 |
| Bulletin 7 | .10 | 2 | .20 | 6 | .60 | 8 | .80 | 9 | .90 | 25 | 2.50 |
| Bulletin 8 | .10 | 3 | .30 | 9 | .90 | 9 | .90 | 9 | .90 | 30 | 3.00 |
| Bulletin 9 | .05 | 2 | .10 | 11 | .55 | 11 | .55 | 9 | .45 | 33 | 1.65 |
| Bulletin 10 | .05 | 10 | .50 | 13 | .65 | 14 | .70 | 7 | .35 | 44 | 2.20 |
| Bulletin 11 | .05 | 5 | .25 | 7 | .35 | 13 | .65 | 8 | .40 | 33 | 1.65 |
| Bulletin 12 | .05 | 1 | .05 | 6 | .30 | 10 | .50 | 5 | .25 | 22 | 1.10 |
| Bulletin 13 | .10 | 4 | .40 | 37 | 3.70 | 14 | 1.40 | 12 | 1.20 | 67 | 6.70 |
| Bulletin 14 | .15 | 3 | .45 | 22 | 3.30 | 13 | 1.95 | 10 | 1.50 | 48 | 7.20 |
| Bulletin 15 | .05 | 6 | .30 | 7 | .35 | 9 | .45 | 6 | .30 | 28 | 1.40 |
| Bulletin 16 | .05 | 7 | .35 | 5 | .25 | 10 | .50 | 7 | .35 | 29 | 1.45 |
| Bulletin 17 | .05 | 4 | .20 | 8 | .40 | 10 | .50 | 9 | .45 | 31 | 1.55 |
| Bulletin 18 | .05 | 5 | .25 | 9 | .45 | 7 | .35 | 10 | .50 | 31 | 1.55 |
| Bulletin 19 | .05 | 4 | .20 | 8 | .40 | 9 | .45 | 9 | .45 | 30 | 1.50 |
| Bulletin 20 | .10 | 5 | .50 | 12 | 1.20 | 17 | 1.70 | 13 | 1.30 | 47 | 4.70 |
| Bulletin 21 | .05 | 4 | .20 | 10 | .50 | 7 | .35 | 8 | .40 | 29 | 1.45 |
| Bulletin 22 | .05 | 6 | .30 | 5 | .25 | 10 | .50 | 6 | .30 | 27 | 1.35 |
| Bulletin 23 | .15 | 9 | 1.35 | 6 | .90 | 12 | 1.80 | 12 | 1.80 | 39 | 5.85 |
| Bulletin 24 | .25 | 4 | 1.00 | 6 | 1.50 | 8 | 2.00 | 6 | 1.50 | 24 | 6.00 |
| Bulletin 25 | .10 | 18 | 1.80 | 36 | 3.60 | 53 | 5.30 | 11 | 1.10 | 118 | 11.80 |
| Bulletin 26 | .10 | 15 | 1.50 | 32 | 3.20 | 32 | 3.20 | 19 | 1.90 | 98 | 9.80 |
| Bulletin 27 | .10 | 7 | .70 | 10 | 1.00 | 12 | 1.20 | 10 | 1.00 | 39 | 3.90 |
| Bulletin 28 | .10 | 7 | .70 | 7 | .70 | 8 | .80 | 10 | 1.00 | 32 | 3.20 |
| Bulletin 29 | .05 | 9 | .45 | 8 | .40 | 14 | .70 | 7 | .35 | 38 | 1.90 |
| Bulletin 30 | .25 | 11 | 2.75 | 13 | 3.25 | 14 | 3.50 | 9 | 2.25 | 47 | 11.75 |
| Bulletin 31 | .15 | 9 | 1.35 | 11 | 1.65 | 8 | 1.20 | 9 | 1.35 | 37 | 5.55 |
| Bulletin 32 | .20 | 55 | 11.00 | 27 | 5.40 | 22 | 4.40 | 16 | 3.20 | 120 | 24.00 |
| Bulletin 33 | .05 | 6 | .30 | 6 | .30 | 15 | .75 | 9 | .45 | 36 | 1.80 |
| Bulletin 34 | .10 | 6 | .60 | 11 | 1.10 | 14 | 1.40 | 7 | .70 | 38 | 3.80 |
| Bulletin 35 | .10 | 11 | 1.10 | 15 | 1.50 | 14 | 1.40 | 9 | .90 | 49 | 4.90 |
| Bulletin 36 | .10 | 10 | 1.00 | 51 | 5.10 | 10 | 1.00 | 11 | 1.10 | 82 | 8.20 |
| Bulletin 37 | .25 | 9 | 2.25 | 20 | 5.00 | 13 | 3.25 | 5 | 1.25 | 47 | 11.75 |
| Bulletin 38 | .05 | 6 | .30 | 9 | .45 | 11 | .55 | 4 | .20 | 30 | 1.50 |
| Bulletin 39 | .10 | 15 | 1.50 | 116 | 11.60 | 37 | 3.70 | 23 | 2.30 | 191 | 19.10 |
| Bulletin 40 | .05 | | | 34 | 1.70 | 17 | .85 | 6 | .30 | 57 | 2.85 |
| Bulletin 41 | .15 | | | | | | | 2 | .30 | 2 | .30 |
| Bulletin 42 | .15 | | | | | | | 46 | 6.90 | 46 | 6.90 |
| Bulletin 44 | .05 | | | | | | | 21 | 1.05 | 21 | 1.05 |
| Mineral Resources, 1882 | .50 | 30 | 15.00 | 21 | 10.50 | 64 | 32.00 | 26 | 13.00 | 141 | 70.50 |
| Mineral Resources, 1883–'84 | .60 | 29 | 17.40 | 32 | 19.20 | 91 | 54.60 | 25 | 15.00 | 177 | 106.20 |
| Mineral Resources, 1885 | .40 | 72 | 28.80 | 63 | 25.20 | 113 | 45.20 | 37 | 14.80 | 285 | 114.00 |
| Mineral Resources, 1886 | .50 | | | | | 404 | 202.00 | 74 | 37.00 | 478 | 239.00 |
| Total | | 461 | 123.25 | 838 | 525.92 | 1,312 | 702.57 | 666 | 340.51 | 3,277 | 1,692.25 |

Whole number of volumes sold, 3,277.
Whole amount received for publications, $1,692.25.

*Free distribution.*—Besides this distribution by sale and exchange 38,870 volumes have been distributed gratuitously; and 2,300 atlas sheets have been supplied to coadjutors or persons of service to the Survey.

This number includes 450 complete sets of Survey publications furnished to the Department of the Interior for distribution to libraries under the following joint resolution:

[PUBLIC RESOLUTION—No. 15.]

[JOINT RESOLUTION to distribute copies of special memoirs and reports of the United States Geological Survey.]

*Resolved by the Senate and House of Representatives of the United States of America in Congress assembled,* That there shall be distributed from the number of special memoirs and reports of the United States Geological Survey now authorized by law one copy of every such publication to every public library which shall be designated to the Secretary of the Interior, as follows: Two public libraries to be designated by each of the Senators from the States respectively, two public libraries by the Representative in Congress from every Congressional district, and two public libraries by the Delegate from every Territory; such public libraries to be additional to those to which the said publications are distributed under existing law.

Approved March 3, 1887.

CORRESPONDENCE.

The correspondence carried on by the division with relation to exchanges, distribution, or sale of publications of the Survey, purchase of books or maps, amounted to 13,434 letters received, a daily average of 44+, and 14,898 letters sent out, a daily average of 48+, during the past year.

One man writes all the letters of this large correspondence; two others file and index both the letters received and the letters sent. One man keeps the complicated accounts of sales, which necessitate over sixty distinct ledger accounts. The exchange system occupies one clerk entirely, and the periodicals-catalogue the most of the time of another. One person catalogues the incoming books and one person revises such work and attends to general library routine.

I am, with respect,

CHAS. C. DARWIN,
*Librarian.*

HON. J. W. POWELL,
*Director U. S. Geological Survey, Washington, D. C.*

## REPORT OF MR. JNO. D. McCHESNEY.

### FINANCIAL STATEMENT.

| | | Geological Survey. | Salaries, office Geological Survey. | Total. |
|---|---|---|---|---|
| Amount appropriated by Congress for work of the U. S. Geological Survey for the fiscal year ending June 30, 1888 | ............ | $467,700.00 | $35,540.00 | $503,240.00 |
| Classification of expenditures made from the appropriation for the fiscal year ending June 30, 1888, viz: | | | | |
| A.—Services | $345,325.09 | ............ | ............ | ............ |
| B.—Traveling expenses | 20,256.58 | ............ | ............ | ............ |
| C.—Transportation of property | 3,894.31 | ............ | ............ | ............ |
| D.—Field subsistence | 11,794.23 | ............ | ............ | ............ |
| E.—Field supplies and expenses | 40,840.36 | ............ | ............ | ............ |
| F.—Field material | 7,753.28 | ............ | ............ | ............ |
| G.—Instruments | 3,049.16 | ............ | ............ | ............ |
| H.—Laboratory material | 3,106.49 | ............ | ............ | ............ |
| I.—Photographic material | 3,681.35 | ............ | ............ | ............ |
| K.—Books and maps | 1,647.08 | ............ | ............ | ............ |
| L.—Stationery and drawing material | 707.99 | ............ | ............ | ............ |
| M.—Illustrations for reports | 49.40 | ............ | ............ | ............ |
| N.—Office rents | 1,809.42 | ............ | ............ | ............ |
| O.—Office furniture | 1,039.83 | ............ | ............ | ............ |
| P.—Office supplies and repairs | 3,446.37 | ............ | ............ | ............ |
| Q.—Storage | 410.40 | ............ | ............ | ............ |
| R.—Correspondence | 287.66 | ............ | ............ | ............ |
| Bonded railroad accounts: | | | | |
| Freight ............ $526.70 | | | | |
| Transportation of assistants 1,286.87 | 1,813.57 | | | |
| Total amount of expenditures Geological Survey | ............ | 450,912.57 | | |
| Amount expended on account appropriation for salaries, Office Geological Survey | 35,139.57 | ............ | 35,139.57 | ............ |
| Total amount of expenses | ............ | 450,912.57 | 35,139.57 | 486,052.14 |
| Balance unexpended | ............ | 16,787.43 | 400.43 | 17,187.86 |
| Amount on hand to meet outstanding liabilities | ............ | 16,787.43 | ............ | ............ |

JNO. D. McCHESNEY,
*Chief Disbursing Clerk U. S. Geological Survey.*

WASHINGTON, D. C., *July* 1, 1888.

HON. J. W. POWELL,
*Director U. S. Geological Survey, Washington, D. C.*

*Abstract of disbursements made by Jno. D. McChesney, chief disbursing clerk, U. S. Geological Survey, during the third quarter of* 1887.

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1887. | | | | |
| July 13 | 1 | S. J. Haislett | Field material | $54.00 |
| 14 | 2 | Washington City post-office | Rent of post-office boxes | 8.00 |
| 16 | 3 | L. C. Schmidt | Services, July 1 to 7, 1887 | 10.00 |
| 20 | 4 | Charles D. Walcott | Traveling expenses | 58.99 |
| 20 | 5 | A. C. Peale | do | 129.70 |
| 21 | 6 | Henry L. Reynold, jr | Services, July 1 to 15, 1887 | 29.35 |
| 21 | 7 | Alvah Bushnell | Stationery | 7.80 |
| 21 | 8 | Quartermaster's Department, U. S. Army | Tents | 278.06 |
| 21 | 9 | J. Bishop & Co | Laboratory supplies and material | 53.72 |
| 22 | 10 | Louisville, New Albany and Chicago Railroad. | Transportation of assistants | 80.50 |
| 22 | 11 | Chicago, Burlington and Quincy Railroad. | do | 16.94 |
| 22 | 12 | W. and L. E. Gurley | Instruments | 90.00 |
| 22 | 13 | R. C. Jones | Publications | 14.00 |
| 23 | 14 | Wyckoff, Seamans & Benedict | Typewriters and repairs | 85.50 |
| 25 | 15 | F. E. Short & Co | 8 mules | 1,165.00 |
| 27 | 16 | H. H. Nichols | Drawings | 8.75 |
| 27 | 17 | Sparks Bros. and Hancock | 2 mules and 1 horse | 525.00 |
| 29 | 18 | Wash. B. Williams | Field material | 5.20 |
| 31 | 19 | Nelson H. Darton | Services, July, 1887 | 100.00 |
| 31 | 20 | Pay-roll of employés | do | 555.02 |
| 31 | 21 | do | do | 3,025.71 |
| 31 | 22 | do | do | 3,005.64 |
| 31 | 23 | do | do | 1,878.72 |
| 31 | 24 | do | do | 756.40 |
| 31 | 25 | Ira Sayles | do | 136.95 |
| 31 | 26 | George W. Shutt | do | 252.70 |
| 31 | 27 | Gilbert Thompson | do | 210.60 |
| 31 | 28 | John H. Renshawe | do | 210.60 |
| 31 | 29 | Anton Karl | do | 168.50 |
| 31 | 30 | H. B. Crosby | do | 25.60 |
| Aug. 1 | 31 | A. C. Peale | do | 168.50 |
| 1 | 32 | R. D. Irving | do | 252.70 |
| 1 | 33 | O. C. Marsh | do | 337.00 |
| 1 | 34 | M. P. Felch | do | 170.00 |
| 1 | 35 | G. Baur | do | 140.00 |
| 1 | 36 | F. Berger | do | 70.00 |
| 1 | 37 | H. Gibb | do | 60.00 |
| 1 | 38 | R. W. Westbrook | do | 55.00 |
| 1 | 39 | L. P. Bush | do | 50.00 |
| 1 | 40 | Sam H. Scudder | do | 210.60 |
| 1 | 41 | H. R. Geiger | do | 126.40 |
| 1 | 42 | Leo Lesquereux | do | 75.00 |
| 1 | 43 | N. S. Shaler | do | 260.00 |
| 1 | 44 | Pay-roll of employés | do | 286.60 |
| 1 | 45 | R. P. Rothwell | do | 75.00 |
| 1 | 46 | Pay-roll of employés | do | 615.60 |
| 1 | 47 | Park & Tilford | Field supplies | 22.95 |
| 1 | 48 | J. J. Foster | Field material | 228.35 |
| 1 | 49 | A. F. Dunnington | Services, July, 1887 | 134.80 |
| 1 | 50 | H. H. Nichols | Services, July 19 to 31, 1887 | 22.00 |
| 1 | 51 | Joseph F. Page | Miscellaneous field supplies | 9.50 |
| 1 | 52 | Washington Gas-Light Company | Gas, July, 1887 | 76.40 |
| 2 | 53 | A. Lamme & Co | Field subsistence | 52.52 |
| 2 | 54 | do | Field supplies | 11.02 |
| 2 | 55 | E. J. Owenhouse | Field material | 10.00 |
| 2 | 56 | J. Henry Blake | Services, July, 1887 | 151.60 |
| 2 | 57 | Horace M. Reeve | Services, July 19 to 31, 1887 | 27.50 |
| 2 | 58 | James G. Bowen | Care and forage of public animals | 70.35 |
| 2 | 59 | Lawrence C. Johnson | Services, July, 1887 | 117.90 |
| 2 | 60 | E. S. Strobhar | Publications | 12.00 |
| 2 | 61 | Theodor Berendsohn | do | 2.10 |
| 3 | 62 | Cottingham Bros | 1 horse | 135.00 |
| 3 | 63 | I. C. Russell | Field expenses | 131.21 |
| 3 | 64 | T. C. Chamberlin | Services, July, 1887 | 78.26 |
| 3 | 65 | B. F. McCaully & Co | Care and forage of public animals | 50.46 |
| 4 | 66 | F. W. Geiger | Services, July 5 to 31, 1887 | 39.19 |
| 6 | 67 | Lawrence C. Johnson | Traveling expenses | 44.75 |
| 6 | 68 | Samuel Lightfoot | Services, July, 1887 | 50.00 |
| 6 | 69 | S. D. Howie | do | 110.00 |
| 6 | 70 | C. R. Van Hise | do | 130.00 |
| 6 | 71 | William M. Fontaine | do | 168.50 |
| 6 | 72 | Charles Oley | do | 90.00 |
| 6 | 73 | Bingham Perrin | Subsistence and supplies | 19.60 |
| 6 | 74 | Walfred Been | Subsistence supplies | 26.75 |
| 6 | 75 | do | do | 22.25 |
| 6 | 76 | C. H. Oppel & Sons | do | 78.46 |

*Abstract of disbursements made by Jno. D. McChesney, etc.*—Continued.

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1887. | | | | |
| Aug. 6 | 77 | William C. Day | Services, July 1 to 30, 1887 | $120.00 |
| 8 | 78 | Fred. Brown | ......do | 160.00 |
| 8 | 79 | J. B. Hatcher | ......do | 160 00 |
| 8 | 80 | J. Brown | ......do | 90.00 |
| 8 | 81 | W. S. Bayley | ......do | 60.00 |
| 8 | 82 | Thomas C. Howie | ......do | 60.00 |
| 8 | 83 | Walfred Been | Field supplies, etc | 3.52 |
| 8 | 84 | John F. Paret | Office supplies | 1.40 |
| 8 | 85 | Pay-roll of employés | Services, July, 1887 | 299.62 |
| 9 | 86 | Robert Robertson | Services, July 1 to 24, 1887 | 38.71 |
| 10 | 87 | Quartermaster's Department, U. S. Army. | Field material | 30.23 |
| 10 | 88 | J. E. Todd | Services, July, 1887 | 100.00 |
| 10 | 89 | George H. Stone | ......do | 125.00 |
| 10 | 90 | P. H. Bevier | Traveling expenses | 79.63 |
| 10 | 91 | P. D. Staats | ......do | 49.50 |
| 10 | 92 | F. W. Bennett | ......do | 94.98 |
| 10 | 93 | Asher Atkinson | ......do | 27.70 |
| 10 | 94 | W. H. Luster, jr | ......do | 60.27 |
| 10 | 95 | Joseph Orsborn | Laboratory material | 6.00 |
| 10 | 96 | Charles S. Cudlip | Photographic material | 94.41 |
| 11 | 97 | Ira Sayles | Traveling expenses | 38.67 |
| 11 | 98 | Richard Thornton | Washing towels | .42 |
| 12 | 99 | Elgin R. L. Gould | Services | 80.00 |
| 12 | 100 | V. Baldwin Johnson | 10 tons of coal | 48.40 |
| 16 | 101 | H. H. Nichols | Services, August 1 to 16, 1887 | 28.00 |
| 17 | 102 | John C. Parker | Office furniture and supplies | 102.00 |
| 17 | 103 | I. C. Russell | Miscellaneous field expenses | 26.30 |
| 17 | 104 | Nelson H. Darton | Traveling expenses | 56.80 |
| 17 | 105 | C. R. Van Hise | ......do | 146.25 |
| 17 | 106 | Bailey Willis | Miscellaneous field expenses | 107.24 |
| 17 | 107 | Robert Robertson | Traveling expenses | 93.20 |
| 18 | 108 | Julius Baumgarten | 1 dating stamp | 5.00 |
| 19 | 109 | Mutual District Messenger Company. | Rental of night watch | 5.00 |
| 19 | 110 | Baltimore and Ohio Telegraph Company. | Telegrams, July, 1887 | .58 |
| 24 | 111 | Oregon and California Railroad Company. | Transportation of assistants | 24.38 |
| 24 | 112 | R. L. Packard | Services | 150.00 |
| 24 | 113 | W. H. Burwell | Services, July, 1887 | 40.00 |
| 24 | 114 | United Lines Telegraph Company | Telegrams, July, 1887 | .52 |
| 24 | 115 | Wyckoff, Seamans & Benedict | Remodeling typewriter | 35.00 |
| 24 | 116 | Pennsylvania Railroad Company | Transportation of assistants | 332.01 |
| 25 | 117 | Henry Gannett | Traveling expenses | 121.77 |
| 26 | 118 | Roland D. Irving | ......do | 132.74 |
| 26 | 119 | ......do | ......do | 120.59 |
| 26 | 120 | H. R. Geiger | ......do | 88.00 |
| 26 | 121 | G. A. Buckstaff | Services, July 12 to August 22, 1887 | 87.50 |
| 26 | 122 | Agatagi | Services, July 19 to August 20, 1887 | 66.00 |
| 26 | 123 | James Carriboo | Services, July 23 to August 20, 1887 | 58.00 |
| 30 | 124 | C. H. Oppel & Sons | Hire of two canoes | 24.00 |
| 31 | 125 | W. N. Merriam | Services, July and August, 1887 | 235.80 |
| 31 | 126 | Sam. H. Scudder | Services, August, 1887 | 210.60 |
| 31 | 127 | A. C. Peale | ......do | 168.50 |
| 31 | 128 | Pay-roll of employés | ......do | 286 60 |
| 31 | 129 | O. C. Marsh | ......do | 337.00 |
| 31 | 130 | J. Henry Blake | ......do | 151.60 |
| 31 | 131 | Pay-roll of employés | ......do | 322.20 |
| 31 | 132 | Roland D. Irving | ......do | 252.70 |
| 31 | 133 | H. R. Geiger | ......do | 126.40 |
| 31 | 134 | F. W. Geiger | ......do | 45.00 |
| 31 | 135 | S. D. Howie | ......do | 110.00 |
| 31 | 136 | W. S. Bayley | ......do | 60.00 |
| 31 | 137 | J. S. Newberry | ......do | 606.60 |
| 31 | 138 | Nelson H. Darton | ......do | 100.00 |
| 31 | 139 | A. F. Dunnington | ......do | 134.80 |
| 31 | 140 | Lester F. Ward | ......do | 168.50 |
| 31 | 141 | George W. Shutt | ......do | 252.70 |
| 31 | 142 | Anton Karl | ......do | 168.50 |
| 31 | 143 | W. H. Holmes | ......do | 202.20 |
| 31 | 144 | Ira Sayles | ......do | 117.90 |
| 31 | 145 | Pay-roll of employés | ......do | 756.40 |
| 31 | 146 | ......do | ......do | 2,437.90 |
| 31 | 147 | ......do | ......do | 1,801.79 |
| 31 | 148 | ......do | ......do | 2,856.20 |
| 31 | 149 | ......do | ......do | 547.90 |
| 31 | 150 | Wyckoff, Seamans & Benedict | 1 typewriter | 90.00 |
| 31 | 151 | L. C. Wooster | Services, August 5 to 27, 1887 | 80.00 |
| 31 | 152 | Alvah Bushnell | Field material | 7.80 |

*Abstract of disbursements made by Jno. D. McChesney, etc.*—Continued.

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1887. | | | | |
| Sept. 1 | 153 | William Kerr | Laboratory material | $18.00 |
| 1 | 154 | R. S. Tarr | Services during August, 1887 | 30.00 |
| 1 | 155 | Atlantic and Pacific Railroad | Transportation of assistants | 8.75 |
| 1 | 156 | Oregon and California Railroad | do | 8.72 |
| 1 | 157 | Baltimore and Ohio Railroad | do | 285.00 |
| 1 | 158 | Northern Pacific Railroad | do | 352.05 |
| 1 | 159 | Washington Gas-Light Company | Gas for August, 1887 | 68.52 |
| 2 | 160 | S. J. Haislett | Field material | 42.90 |
| 2 | 161 | Melville Lindsey | Field supplies | 4.50 |
| 2 | 162 | George Ryneal, jr | Office and photographic supplies | 7.25 |
| 2 | 163 | Robert E. C. Stearns | Services, August, 1887 | 168.50 |
| 2 | 164 | Gilbert Thompson | do | 210.60 |
| 2 | 165 | Pay-roll of employés | do | 601.42 |
| 2 | 166 | G. Baur | do | 140.00 |
| 2 | 167 | F. Berger | do | 70.00 |
| 2 | 168 | H. Gibb | do | 60.00 |
| 3 | 169 | Charles D. Wolcott | do | 168.50 |
| 3 | 170 | Fred Brown | do | 140.00 |
| 3 | 171 | Collier Cobb | Services, August 15 to 31, 1887 | 27.41 |
| 3 | 172 | Royce & Marean | Laboratory supplies | 4.30 |
| 3 | 173 | F. G. Alexander | do | 3.00 |
| 3 | 174 | J. & H. Berge | do | 27.01 |
| 3 | 175 | Emil Greiner | do | 4.25 |
| 3 | 176 | Wash. B. Williams | Field material | 5.20 |
| 3 | 177 | Baltimore and Ohio Railroad | Transportation of assistants | 65.10 |
| 3 | 178 | Little Rock and Fort Smith Railway. | do | 5.15 |
| 5 | 179 | W. M. Hosier | Publications | 30.00 |
| 6 | 180 | J. G. Bowen | Care and forage of public animals | 72.35 |
| 6 | 181 | W. C. Day | Services, August 1 to 29, 1887 | 100.00 |
| 6 | 182 | J. B. Hatcher | Services, August, 1887 | 160.00 |
| 6 | 183 | George Nevins | do | 90.00 |
| 6 | 184 | L. P. Bush | do | 50.00 |
| 6 | 185 | W. H. Burwell | do | 40.00 |
| 6 | 186 | William M. Fontaine | do | 168.50 |
| 6 | 187 | St. Louis and San Francisco Railway. | Transportation of assistants | 9.90 |
| 6 | 188 | Darling, Brown & Sharpe | Instruments | 60.00 |
| 6 | 189 | Buffalo Dental Company | Laboratory supplies | 32.80 |
| 6 | 190 | W. J. McGee | Traveling expenses | 105.24 |
| 6 | 191 | Harris Mopkins | do | 12.11 |
| 7 | 192 | I. C. Russell | Miscellaneous field expenses | 98.72 |
| 7 | 193 | Eimer & Amend | Laboratory supplies | 14.15 |
| 7 | 194 | Charles H. Kraft | do | 33.70 |
| 8 | 195 | Madeline D. Routh | Services, August 1 to 11, 1887 | 21.52 |
| 9 | 196 | Horace M. Reeve | Services, August, 1887 | 67.50 |
| 8 | 197 | Capt. C. E. Dutton | Traveling expenses | 29.10 |
| 9 | 198 | F. W. Bennett | do | 87.15 |
| 9 | 199 | Asher Atkinson | do | 38.46 |
| 9 | 200 | P. D. Staats | do | 37.89 |
| 9 | 201 | W. H. Luster, jr | do | 31.23 |
| 9 | 202 | P. H. Bevier | do | 86.73 |
| 10 | 203 | William D. Castle | Field material | 5.00 |
| 10 | 204 | Shepherd & Hurley | Laboratory supplies | 54.50 |
| 12 | 205 | Western Union Telegraph Company. | Telegrams, July, 1887 | 35.80 |
| 12 | 206 | J. E. Todd | Services, August, 1887 | 130.00 |
| 12 | 207 | N. S. Shaler | do | 270.00 |
| 12 | 208 | R. S. Tarr | Services, July, 1887 | 30.00 |
| 12 | 209 | Robert T. Hill | Traveling expenses | 15.75 |
| 12 | 210 | N. Y. Central and Hudson River Railroad. | Transportation of assistants | 31.50 |
| 12 | 211 | F. A. Green & Co | Subsistence supplies | 26.72 |
| 12 | 212 | do | do | 25.76 |
| 12 | 213 | do | do | 6.90 |
| 12 | 214 | do | do | 8.50 |
| 13 | 215 | L. H. Schneider's Son | Laboratory supplies | 31.33 |
| 13 | 216 | do | do | 12.00 |
| 13 | 217 | Charles S. Cudlip | Photographic supplies | 59.90 |
| 13 | 218 | Thomas Parry | Services, September 1 to 12, 1887 | 14.00 |
| 14 | 219 | Newport News and Mississippi Valley Railroad. | Transportation of assistants | 61.90 |
| 15 | 220 | Z. D. Gilman | Photo. and laboratory supplies | 215.84 |
| 15 | 221 | Mutual District Messenger Company | Rental of night watch | 5.00 |
| 15 | 222 | William B. Lane | Traveling expenses | 21.50 |
| 15 | 223 | W. M. Shuster & Son | Office supplies | 68.60 |
| 15 | 224 | J. F. Sabine | Publications | 4.00 |
| 15 | 225 | Edward J. Hannan | Photo. material | 100.00 |
| 16 | 226 | John B. Rogers | Services, September 1 to 16, 1887 | 36.52 |

*Abstract of disbursements made by Jno. D. McChesney, etc.*—Continued.

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1887. | | | | |
| Sept. 17 | 227 | Atlantic and Pacific Railroad | Transportation of freight | $28.78 |
| 17 | 228 | Robert T. Hill | Traveling expenses | 11.75 |
| 17 | 229 | H. R. Geiger | do | 66.40 |
| 17 | 230 | Ira Sayles | do | 50.88 |
| 17 | 231 | Thomas C. Howie | Services, August, 1887 | 60.00 |
| 17 | 232 | C. R. Van Hise | do | 135.00 |
| 17 | 233 | Charles Oley | do | 90.00 |
| 17 | 234 | Samuel Lightfoot | Services, August 5 to 27, 1887 | 36.29 |
| 17 | 235 | Spencer Bros | Field material | 12.50 |
| 17 | 236 | A. G. Gedney | Office furniture and supplies | 26.00 |
| 17 | 237 | Z. D. Gilmau | Laboratory supplies | 14.66 |
| 17 | 238 | Edwin B. Garges | 1 bay horse | 185.00 |
| 19 | 239 | George William Cook | Services, July 5 to August 27, 1887 | 104.51 |
| 20 | 240 | Henry Gannett | Traveling expeuses | 61.57 |
| 20 | 241 | Thomas M. Chatard | Services, August, 1887 | 134.80 |
| 20 | 242 | M. P. Felch | do | 170.00 |
| 29 | 243 | Thomas Hampson | Traveling expenses | 41.30 |
| 29 | 244 | I. C. Russell | do | 66.25 |
| 29 | 245 | do | Miscellaneous field expeuses | 12.75 |
| 30 | 246 | Noah R. King | Services, July 11 to September 26, 1887. | 112.50 |
| 30 | 247 | Charles D. Lunghrey | do | 150.00 |
| 30 | 248 | James Forristell | do | 208.50 |
| 30 | 249 | G. F. Becker | Services, July 1 to September 30, 1887. | 1,000.00 |
| 30 | 250 | T. A. Bostwick | do | 225.00 |
| 30 | 251 | A. Hermann | do | 225.00 |
| 30 | 252 | Ira Sayles | Services, September, 1887 | 114.20 |
| 30 | 253 | Lawrence C. Johnson | do | 114.20 |
| 30 | 254 | A. C. Peale | do | 163.00 |
| 30 | 255 | Robert T. Hill | do | 97.80 |
| 30 | 256 | H. R. Geiger | do | 122.20 |
| 30 | 257 | F. W. Geiger | do | 45.00 |
| 30 | 258 | J. Henry Blake | do | 146.80 |
| 30 | 259 | Sam H. Scudder | do | 203.80 |
| 30 | 260 | O. C. Marsh | do | 326.00 |
| 30 | 261 | J. B. Hatcher | do | 210.00 |
| 30 | 262 | G. Baur | do | 140.00 |
| 30 | 263 | F. Berger | do | 70.00 |
| 30 | 264 | H. Gibb | do | 60.00 |
| 30 | 265 | L. P. Bush | do | 50.00 |
| 30 | 266 | Philip C. Warman | do | 130.40 |
| 30 | 267 | A. F. Dunnington | do | 130.40 |
| 30 | 268 | Robert E. C. Stearns | do | 163.00 |
| 30 | 269 | Gilbert Thompson | do | 203.80 |
| 30 | 270 | W. H. Holmes | do | 195.60 |
| 30 | 271 | Anton Karl | do | 163.00 |
| 30 | 272 | Pay-roll of employés | do | 327.43 |
| 30 | 273 | do | do | 847.31 |
| 30 | 274 | do | do | 2,294.00 |
| 30 | 275 | do | do | 2,901.00 |
| 30 | 276 | do | do | 1,734.33 |
| 30 | 277 | Lester F. Ward | do | 163.00 |
| 30 | 278 | Roland D. Irving | do | 244.60 |
| 30 | 279 | George W. Shutt | do | 244.60 |
| 30 | 280 | John R. Proctor | Services, July 1 to September 1, 1887. | 140.00 |
| 30 | 281 | J. S. Brown | Services, July 23 to August 31, 1887 | 102.00 |
| 30 | 282 | Paul Roessler | Instruments | 60.91 |
| 30 | 283 | Bangs & Co | Publications | 3.00 |
| 30 | 284 | Hannibal and Saint Joseph Railroad. | Transportation of assistants | 6.15 |
| 30 | 285 | Chicago, Burlingtou, and Quincy Railroad. | do | 46.10 |
| 30 | 286 | Baltimore and Ohio Railroad | do | 24.50 |
| 30 | 287 | Robert Cameron | Field material, etc | 21.85 |
| 30 | 288 | do | do | 74.90 |
| 30 | 289 | E. J. Post & Co | do | 97.30 |
| 30 | 290 | do | do | 40.60 |
| 30 | 291 | L. B. Putuey | 1 horse | 125.00 |
| 30 | 292 | R. R. Gurley | Traveling expenses | 20.80 |
| 30 | 293 | Washington Gas-Light Company. | Gas for September, 1887 | 70.39 |
| 30 | 294 | Washington City post-office | Rent of post-offices boxes | 8.00 |
| 30 | 295 | Charles D. Walcott | Services, September, 1887 | 163.00 |
| 30 | 296 | C. W. Hayes | do | 50.00 |
| 30 | 297 | Pay-roll of employés | do | 315.60 |
| 30 | 298 | Annie S. Morehead | Services, September 1 to 14, 1887 | 22.83 |
| 30 | 299 | W. P. Rust | Services, July 1 to September 30 | 256.75 |
| 30 | 300 | Bailley Willis | Miscellaneous field expenses | 90.34 |
| 30 | 301 | Thomas M. Chatard | Traveling expeuses | 257.15 |
| 30 | 302 | W. J. McGee | do | 97.27 |

*Abstract of disbursements by Jno. D. McChesney, etc.* —Continued.

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1887. | | | | |
| Sept. 30 | 303 | James G. Bowen | Care and forage of public animals | $74.87 |
| 30 | 304 | A. Lamme & Co | Field supplies | 12.73 |
| 30 | 305 | ..... do | ..... do | 74.87 |
| 30 | 306 | Adams Express Company | Freight charges, July, 1887 | 448.55 |
| 30 | 307 | Western Union Telegraph Company. | Telegrams for August, 1887 | 12.33 |
| 30 | 308 | Chesapeake and Potomac Telephone Company. | Services, July 1 to September 30, 1887. | 155.50 |
| 30 | 309 | Nelson H. Darton | Services, September, 1887 | 100.00 |
| 30 | 310 | William M. Fontaine | ..... do | 163.00 |
| 30 | 311 | George W. Lord | Office supplies | 15.35 |
| | | Total | | 57,598.45 |

SALARIES OFFICE OF GEOLOGICAL SURVEY.

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1887. | | | | |
| July 14 | 1 | John C. Collins | Salary, July 1 to 7, 1887 | 9.23 |
| 31 | 2 | A. B. Searle | ..... do | 75.80 |
| 31 | 3 | Pay-roll of employés | Services, July, 1887 | 2,877.03 |
| 17 | 4 | Clayborn Lamar Gatewood | Services, July 1–17, 1887 | 22.17 |
| Aug. 31 | 5 | G. P. Marvine | Services, August, 1887 | 60.60 |
| 31 | 6 | A. B. Searle | ..... do | 75.80 |
| 31 | 7 | Pay-roll of employés | ..... do | 2,856.80 |
| Sept. 10 | 8 | D. W. Norton | Services, September 1–10, 1887 | 13.04 |
| 30 | 9 | Patrick Wheeler | ..... do | 49.00 |
| 30 | 10 | A. B. Searle | ..... do | 73.40 |
| 30 | 11 | Pay-roll of employes | ..... do | 2,722.58 |
| | | Total | | 8,835.45 |

*Abstract of disbursements made by C. D. Davis, special disbursing agent, U. S. Geological Survey, during the third quarter of 1887.*

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1887. | | | | |
| July 20 | 1 | E. W. F. Natter | Miscellaneous field expenses | 110.50 |
| 20 | 2 | William H. Lovell | ..... do | 39.07 |
| 20 | 3 | R. D. Cummin | ..... do | 30.90 |
| 20 | 4 | Clifford Arrick | ..... do | 52.70 |
| 20 | 5 | C. C. Bassett | ..... do | 53.60 |
| 21 | 6 | R. D. Cummin | ..... do | 27.03 |
| 21 | 7 | E. B. Clark | ..... do | 35.50 |
| 26 | 8 | Clifford Arrick | do | 70.98 |
| 27 | 9 | John B. Rogers | Traveling expenses | 6.50 |
| 27 | 10 | D. J. Howell | ..... do | 13.57 |
| 31 | 11 | William H. Lovell | Services, July, 1887 | 80.44 |
| 31 | 12 | G. L. Johnson | ..... do | 50.00 |
| 31 | 13 | Laurence Thompson | ..... do | 83.43 |
| 31 | 14 | C. J. Akin | ..... do | 50.00 |
| 31 | 15 | Charles C. Bassett | ..... do | 84.20 |
| 31 | 16 | W. E. Horton | ..... do | 50.00 |
| 31 | 17 | E. B. Clark | ..... do | 75.80 |
| 31 | 18 | Lawson Sandford | ..... do | 50.00 |
| 31 | 19 | R. D. Cummin | ..... do | 101.10 |
| 31 | 20 | James Longstreet, jr | ..... do | 50.50 |
| 31 | 21 | Pay-roll of employés | ..... do | 1,080.53 |
| 31 | 22 | MacGregor Jenkins | ..... do | 38.71 |
| Aug 1 | 23 | Laurence Thompson | Miscellaneous field expenses | 39.31 |
| 1 | 24 | S. H. Bodfish | ..... do | 64.30 |
| 1 | 25 | ..... do | Traveling expenses | 34.07 |
| 2 | 26 | Henry Ulke, jr | ..... do | 15.60 |
| 4 | 27 | Marcus Baker | ..... do | 63.11 |
| 5 | 28 | C. C. Bassett | Miscellaneous field expenses | 80.19 |
| 5 | 29 | R. D. Cummin | ..... do | 57.80 |
| 6 | 30 | C. D. Davis | Traveling expenses | 22.05 |
| 6 | 31 | E. W. F. Natter | ..... do | 9.41 |
| 8 | 32 | D. J. Howell | ..... do | 16.65 |
| 9 | 33 | R. H. Hale | ..... do | 17.81 |
| 9 | 34 | Robert Robertson | Services, July 25 to 31, 1887 | 11.29 |
| 9 | 35 | E. B. Clark | Miscellaneous field expenses | 72.00 |
| 9 | 36 | Clifford Arrick | ..... do | 20.70 |
| 11 | 37 | William H. Lovell | ..... do | 55.66 |

*Abstract of disbursements made by C. D. Davis, etc.*—Continued.

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1887. | | | | |
| Aug. 12 | 38 | E. B. Clark | Traveling expenses | $10.30 |
| 17 | 39 | Laurence Thompson | Miscellaneous field expenses | 100.02 |
| 17 | 40 | E. W. F. Natter | Traveling expenses | 28.98 |
| 17 | 41 | E. C. Robinson | Transportation | 200.00 |
| 18 | 42 | William H. Lovell | Miscellaneous field expenses | 20.18 |
| 18 | 43 | E. B. Clark | ......do | 69.00 |
| 20 | 44 | Willard D. Johnson | ......do | 92.27 |
| 20 | 45 | ......do | Traveling expenses | 44.14 |
| 20 | 46 | Clifford Arrick | ......do | 8.71 |
| 22 | 47 | E. W. F. Natter | Miscellaneous field expenses | 149.67 |
| 23 | 48 | Robert D. Cummin | ......do | 53.05 |
| 29 | 49 | E. W. F. Natter | ......do | 290.30 |
| 31 | 50 | Laurence Thompson | Services, August, 1887 | 84.20 |
| 31 | 51 | C. J. Akin | ......do | 50.00 |
| 31 | 52 | Sumner H. Bodfish | ......do | 168.50 |
| 31 | 53 | McGregor Jenkins | ......do | 50.00 |
| 31 | 54 | Charles C. Bassett | ......do | 84.20 |
| 31 | 55 | James Longstreet, jr | ......do | 50.50 |
| 31 | 56 | Robert D. Cummin | ......do | 101.10 |
| 31 | 57 | Lawson Sandford | ......do | 50.00 |
| 31 | 58 | E. B. Clark | ......do | 75.80 |
| 31 | 59 | W. E. Horton | ......do | 50.00 |
| 31 | 60 | William H. Lovell | ......do | 84.20 |
| 31 | 61 | G. L. Johnson | ......do | 50.00 |
| 31 | 62 | Pay-roll of employés | ......do | 1,168.60 |
| Sept. 6 | 63 | C. C. Bassett | Miscellaneous field expenses | 135.10 |
| 6 | 64 | W. H. Lovell | ......do | 69.66 |
| 6 | 65 | Pearce Prentiss | Services, August 22 to 31, 1887 | 16.13 |
| 6 | 66 | Frank L. Wagner | Services, August 25 to 31, 1887 | 6.77 |
| 8 | 67 | Willard D. Johnson | Miscellaneous field expenses | 119.93 |
| 8 | 68 | Robert. D. Cummin | ......do | 61.39 |
| 8 | 69 | E. B. Clark | ......do | 80.00 |
| 8 | 70 | E. W. F. Natter | Traveling expenses | 28.86 |
| 9 | 71 | S. H. Bodfish | Miscellaneous field expenses | 177.28 |
| 10 | 72 | Laurence Thompson | ......do | 78.57 |
| 13 | 73 | S. H. Bodfish | Traveling expenses | 36.17 |
| 15 | 74 | Marcus Baker | ......do | 97.60 |
| 17 | 75 | E. W. F. Natter | ......do | 13.10 |
| 17 | 76 | ......do | Miscellaneous field expenses | 264.88 |
| 20 | 77 | E. C. Robinson | Field transportation | 200.00 |
| 22 | 78 | E. B. Clark | Miscellaneous field expenses | 52.50 |
| 23 | 79 | Robert D. Cummin | ......do | 52.66 |
| 23 | 80 | Willard D. Johnson | ......do | 104.55 |
| 24 | 81 | E. W. F. Natter | ......do | 259.75 |
| 26 | 82 | Charles C. Bassett | Traveling expenses | 1.30 |
| 27 | 83 | Laurence Thompson | Miscellaneous field expenses | 48.67 |
| 28 | 84 | W. H. Lovell | ......do | 52.92 |
| 27 | 85 | C. C. Bassett | ......do | 68.15 |
| | | | | 7,974.67 |

*Abstract of disbursements made by Mark B. Kerr, disbursing agent, U. S. Geological Survey, during the third quarter of* 1887.

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1887. | | | | |
| July 11 | 1 | Robert H. Chapman | Field expenses | $45.20 |
| 15 | 2 | Hamilton S. Wallace | Traveling expenses | 21.15 |
| 15 | 3 | ......do | Services, July, 1887 | 57.07 |
| 15 | 4 | Frank Tweedy | Traveling expenses | 54.00 |
| 15 | 5 | H. Black | Field expenses | 20.00 |
| 15 | 6 | C. H. Fitch | Traveling expenses | 19.75 |
| 15 | 7 | Fitz D. Ermentrout | ......do | 26.50 |
| 15 | 8 | E. M. Douglas | ......do | 25.10 |
| 16 | 9 | R. U. Goode | ......do | 20.20 |
| 17 | 10 | Charles F. Urquhart | ......do | 19.90 |
| 17 | 11 | J. C. Pierce | Forage | 22.60 |
| 16 | 12 | Highsmith & Beam | Field expenses | 61.60 |
| 17 | 13 | A. Lamme & Co | Field subsistence, etc | 114.26 |
| 17 | 14 | ......do | Field supplies, etc | 15.18 |
| 17 | 15 | E. J. Owenhouse | Field supplies | 22.00 |
| 17 | 16 | John H. Hughes | ......do | 80.92 |
| 17 | 17 | Mandel Bros. & Co | ......do | 31.92 |
| 18 | 18 | Goldberg, Bowen & Co | Field subsistence, etc | 33.80 |
| 18 | 19 | Robert Muldrow | Traveling expenses | 18.35 |

*Abstract of disbursements made by Mark B. Kerr, etc.*—Continued.

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1887. | | | | |
| July 18 | 20 | Frank H. Thorp | Traveling expenses | $40.85 |
| 18 | 21 | Frank E. Gove | ......do | 19.95 |
| 18 | 22 | E. M. Hasbrouck | ......do | 20.85 |
| 18 | 23 | Owen W. Thomas, jr | ......do | 90.80 |
| 19 | 24 | H. M. Wilson | Field expenses | 154.55 |
| 19 | 25 | ......do | ......do | 92.21 |
| 19 | 26 | Redick H. McKee | ......do | 82.70 |
| 19 | 27 | M. J. Holt | Traveling expenses | 82.45 |
| 19 | 28 | Paul Holman | ......do | 41.75 |
| 19 | 29 | H. M. Wilson | Field expenses | 209.41 |
| 19 | 30 | Weatherwax & Culbertson | Field supplies | 29.35 |
| 19 | 31 | N. Wonderly | Repairs, etc | 26.00 |
| 19 | 32 | L. Laudecker | Field subsistence, etc | 26.43 |
| 19 | 33 | John W. Dench | Field material | 97.27 |
| 21 | 34 | Mark B. Kerr | Traveling expenses | 147.35 |
| 22 | 35 | Wells, Fargo & Co | Expressage | 60.50 |
| 22 | 36 | George Engle | Subsistence, etc | 86.10 |
| 23 | 37 | S. F. Moraine | Repairs, etc | 36.80 |
| 23 | 38 | W. W. Kentnor | Field expenses | 16.00 |
| 23 | 39 | D. R. & E. V. Mills | Field supplies | 10.70 |
| 23 | 40 | George H. Currey | Field subsistence, etc | 10.90 |
| 23 | 41 | H. Judge | Field expenses | 44.25 |
| 22 | 42 | Thompson & Stephenson | ......do | 11.25 |
| 23 | 43 | Boyd T. Dickenson | Field subsistence | 7.45 |
| 23 | 44 | H. C. Myer | Field material, etc | 16.65 |
| 23 | 45 | E. T. Perkins, jr | Traveling expenses | 65.30 |
| 23 | 46 | E. Barton | Field expenses | 61.30 |
| 23 | 47 | Darby, Canthen & Co | Field subsistence, etc | 252.93 |
| 23 | 48 | Hurlburt & Semple | Field supplies, etc | 19.50 |
| 23 | 49 | W. S. Greer | Field supplies | 68.85 |
| 23 | 50 | J. E. Knight | Field material | 170.00 |
| 23 | 51 | E. J. Post & Co | Field supplies | 63.40 |
| 23 | 52 | R. D. Cunningham | Field material | 87.00 |
| 23 | 53 | Lincoln Martin | Traveling expenses | 30.90 |
| 23 | 54 | E. M. Douglas | Field expenses | 22.90 |
| 23 | 55 | William L. Laurence | Field supplies | 38.50 |
| 27 | 56 | U. S. Subsistence Department | Field subsistence | 71.02 |
| 27 | 57 | R. U. Goode | Field expenses | 58.22 |
| 27 | 58 | C. H. Fitch | ......do | 90.63 |
| 27 | 59 | Goldberg, Bowen & Co | Field subsistence | 74.35 |
| 27 | 60 | Truman, Isham & Hooker | Two buckboards | 140.00 |
| Aug. 3 | 61 | A. H. Thompson | Services, July, 1887 | 227.40 |
| July 31 | 62 | Pay-roll (H. S. Wallace) | ......do | 225.61 |
| Aug. 2 | 63 | Pliny V. S. Bartlett | ......do | 14.51 |
| 1 | 64 | D. W. Spence | ......do | 20.97 |
| July 31 | 65 | Pay-roll (C. H. Fitch) | ......do | 274.16 |
| Aug. 2 | 66 | E. C. Ryan | Board and lodging | 26.00 |
| 2 | 67 | ......do | Services, July, 1887 | 60.00 |
| 3 | 68 | A. T. Kyle, jr | Pasturage | 18.77 |
| 3 | 69 | ......do | Services, July, 1887 | 13.55 |
| 3 | 70 | ......do | Storage | 1.93 |
| 3 | 71 | Mark B. Kerr | Services, July, 1887 | 151.60 |
| 8 | 72 | George W. McKee | Board and lodging | 25.00 |
| 3 | 73 | Eugene Ricksecker | Field expenses | 388.65 |
| 3 | 74 | H. M. Wilson | ......do | 36.65 |
| 3 | 75 | R. H. Chapman | ......do | 34.85 |
| 3 | 76 | ......do | Traveling expenses | 22.00 |
| 3 | 77 | Arthur P. Davis | Field expenses | 64.48 |
| 3 | 78 | J. S. Diller | ......do | 113.87 |
| 3 | 79 | ......do | Traveling expenses | 75.25 |
| 3 | 80 | Leonard H. Swett | ......do | 28.50 |
| 3 | 81 | Pay-roll (J. S. Diller) | Services, July, 1887 | 199.99 |
| 3 | 82 | A. F. Dunnington | Field expenses | 53.20 |
| 3 | 83 | Redick H. McKee | ......do | 66.30 |
| 3 | 84 | R. H. Chapman | ......do | 31.88 |
| 3 | 85 | E. J. Post & Co | Field supplies | 65.72 |
| 3 | 86 | L. B. Putney | Field subsistence | 158.31 |
| 3 | 87 | Goldberg, Bowen & Co | ......do | 85.63 |
| July 31 | 88 | Pay-roll (A. P. Davis) | Services, July, 1887 | 701.85 |
| 31 | 89 | Pay-roll (E. M. Douglas) | ......do | 659.45 |
| 31 | 90 | Pay-roll (H. M. Wilson) | ......do | 647.77 |
| Aug. 15 | 91 | Mark B. Kerr | Traveling expenses | 44.72 |
| 5 | 92 | E. M. Douglas | Field expenses | 71.89 |
| 6 | 93 | Mandel Bros. & Co | Field supplies | 45.29 |
| 6 | 94 | H. S. Wallace | Field expenses | 74.01 |
| 6 | 95 | William Fernald | Field supplies | 14.25 |
| 6 | 96 | R. U. Goode | Field expenses | 80.37 |
| July 31 | 97 | Pay-roll (R. U. Goode) | Services, July, 1887 | 301.60 |
| Aug. 8 | 98 | C. H. Fitch | Field expenses | 55.78 |

*Abstract of disbursements made by Mark B. Kerr, etc.*—Continued.

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1887. | | | | |
| Aug. 8 | 99 | McMillan & McLellan | Field material | $86.00 |
| 8 | 100 | John H. Hughes | ......do | 22.25 |
| 8 | 101 | H. M. Wilson | Field expenses | 92.85 |
| 9 | 102 | A. F. Dunnington | ......do | 27.15 |
| 9 | 103 | Redick H. McKee | ......do | 26.27 |
| July 31 | 104 | Pay-roll (F. J. Knight) | Services, July, 1887 | 396.42 |
| Aug. 10 | 105 | Paul Holman | ......do | 70.80 |
| 13 | 106 | E. J. Post & Co | Field supplies | 92.58 |
| 13 | 107 | Darby, Canthen & Co | ......do | 21.10 |
| 13 | 108 | Fred. J. Knight | Field expenses | 91.27 |
| 15 | 109 | J. M. Coleman | Field supplies | 6.85 |
| 13 | 110 | H. M. Wilson | Field expenses | 60.90 |
| 15 | 111 | I. W. Denton | Field material | 66.50 |
| 15 | 112 | L. B. Putney | ......do | 138.19 |
| 15 | 113 | ......do | Field subsistence, etc | 95.31 |
| 15 | 114 | Owen W. Thomas, jr | Services, July, 1887 | 50.00 |
| 15 | 115 | Chas. W. Howell | ......do | 60.00 |
| 15 | 116 | Frank Tweedy | Field expenses | 10.50 |
| 15 | 117 | C. E. Mininger | ......do | 4.00 |
| 15 | 118 | N. C. Massey | Board and lodging | 4.51 |
| 15 | 119 | F. E. Short & Co | Forage | 34.30 |
| 15 | 120 | Sullivan B. Newton | Field material | 80.00 |
| 15 | 121 | C. D. Rice | Field expenses | 6.50 |
| 15 | 122 | W. S. Moore | Field material | 65.00 |
| 15 | 123 | Frank Jarvis | Services, July, 1887 | 16.00 |
| 15 | 124 | A. H. Thompson | Field expenses | 21.01 |
| 20 | 125 | ......do | Traveling expenses | 152.90 |
| 20 | 126 | C. P. Rock | Services, July, 1887 | 39.19 |
| 22 | 127 | W. W. McCullough | Field subsistence, etc | 21.66 |
| 22 | 128 | A. F. Dunnington | Field expenses | 39.01 |
| 22 | 129 | L. B. Putney | Forage | 22.52 |
| 22 | 130 | R. U. Goode | Field expenses | 51.00 |
| 22 | 131 | ......do | ......do | 48.53 |
| 22 | 132 | E. M. Douglas | ......do | 52.02 |
| 22 | 133 | Frank E. Gore | ......do | 27.45 |
| 22 | 134 | H. M. Wilson | ......do | 58.91 |
| 23 | 135 | J. Jndell | Field material | 92.50 |
| 24 | 136 | A. Lamme & Co | Field subsistence | 46.91 |
| 25 | 137 | A. F. Dunnington | Field expenses | 46.85 |
| 25 | 138 | R. H. McKee | ......do | 34.85 |
| 31 | 139 | Pay-roll (H. S. Wallace) | Services, August, 1887 | 332.90 |
| 31 | 140 | Pay-roll (R. U. Goode) | ......do | 337.40 |
| 31 | 141 | Pay-roll (C. H. Fitch) | ......do | 314.80 |
| 31 | 142 | Pay-roll (F. J. Knight | ......do | 429.00 |
| 31 | 143 | Pay-roll (Frank Tweedy) | ......do | 344.80 |
| 31 | 144 | Pay-roll (E. M. Douglas) | ......do | 413.50 |
| 31 | 145 | Pay-roll (A. P. Davis) | ......do | 582.30 |
| 31 | 146 | Arthur P. Davis | Field expenses | 110.78 |
| 31 | 147 | Pay-roll (H. M. Wilson) | Services, August, 1887 | 309.50 |
| 31 | 148 | Eugene Ricksecker | Services and field expenses | 454.65 |
| 31 | 149 | Pay-roll (Eugene Ricksecker) | Services, August, 1887 | 289.80 |
| 31 | 150 | Pay-roll (A. F. Dunnington) | ......do | 185.00 |
| 31 | 151 | Ah Ping (Chinese cook) | ......do | 31.00 |
| 31 | 152 | E. C. Ryan | ......do | 60.00 |
| 31 | 153 | ......do | Field expenses | 37.77 |
| 31 | 154 | D. W. Spence | Services, August, 1887 | 50.00 |
| 31 | 155 | C. H. Fitch | Field expenses | 25.50 |
| 31 | 156 | Harry J. Montgomery | Services, August, 1887 | 7.50 |
| 31 | 157 | John Black | ......do | 77.42 |
| 31 | 158 | H. S. Wallace | Field expenses | 49.35 |
| 31 | 159 | E. M. Hasbrouck | ......do | 24.90 |
| 31 | 160 | John H. Hughes | Field supplies | 31.85 |
| 31 | 161 | George W. McKee | Board and lodging | 19.35 |
| 31 | 162 | A. H. Thompson | Services, August, 1887 | 227.40 |
| 31 | 163 | Mark B. Kerr | ......do | 151.60 |
| 31 | 164 | Redick H. McKee | Field expenses | 33.14 |
| 31 | 165 | A. F. Dunnington | ......do | 31.04 |
| 31 | 166 | Pay-roll (J. S. Diller) | Services, August, 1887 | 291.60 |
| 31 | 167 | Pay-roll (McKee) | ......do | 326.10 |
| Sept. 6 | 168 | Redick H. McKee | Field expenses | 34.37 |
| 6 | 169 | Arthur Watts | Services, August, 1887 | 75.00 |
| 6 | 170 | Frank E. Gore | Field expenses | 19.55 |
| 6 | 171 | James T. Jones | Services, August, 1887 | 16.13 |
| 6 | 172 | C. H. Fitch | Field expenses | 27.60 |
| 7 | 173 | A. T. Kyle, jr | Herding, August, 1887 | 35.00 |
| 7 | 174 | ......do | Storage, August, 1887 | 5.00 |
| 7 | 175 | ......do | Pasture, August, 1887 | 8.45 |
| 7 | 176 | Redick H. McKee | Field expenses | 28.57 |
| 7 | 177 | A. F. Dunnington | ......do | 37.64 |
| 7 | 178 | Frank Tweedy | ......do | 14.35 |

*Abstract of disbursements made by Mark B. Kerr, etc.*—Continued.

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1887. | | | | |
| Sept. 7 | 179 | E. M. Douglas | Field expenses | $46.67 |
| 10 | 180 | Thomas M. Chatard | Services, July, 1887 | 134.80 |
| 12 | 181 | G. Huston | 1 mule | 100.00 |
| 12 | 182 | J. F. and J. Nutt | Field subsistence | 39.70 |
| 12 | 183 | R. U. Goode | Field expenses | 51.35 |
| 12 | 184 | ......do | ......do | 50.25 |
| 13 | 185 | A. F. Dunnington | ......do | 18.90 |
| 13 | 186 | E. J. Post & Co | Field supplies | 16.75 |
| 13 | 187 | ......do | ......do | 36.65 |
| 15 | 188 | Pay-roll (A. P. Davis) | Services, August, 1887 | 220.00 |
| 15 | 189 | Redick H. McKee | Field expenses | 14.05 |
| 15 | 190 | John S. Staniels | Board and lodging | 45.00 |
| 17 | 191 | A. H. Thompson | Traveling expenses | 97.90 |
| 17 | 192 | J. A. Wilson | Field material | 56.00 |
| 19 | 193 | H. M Wilson | Field expenses | 137.15 |
| 19 | 194 | R. H. Chapman | ......do | 26.05 |
| 19 | 195 | Joseph Banks | Services, August, 1887 | 31.50 |
| 19 | 196 | C. H. Fitch | Field expenses | 64.65 |
| 20 | 197 | A. Grumfeld | Field supplies | 9.24 |
| 21 | 198 | Redick H. McKee | Field expenses | 37.32 |
| 21 | 199 | A. F. Dunnington | ......do | 51.28 |
| 21 | 200 | E. J. Post & Co | Field supplies | 11.95 |
| 23 | 201 | A. Lietz & Co | Repairs, etc | 42.00 |
| 23 | 202 | C. Beach | Field supplies | 37.39 |
| 27 | 203 | A. F. Dunnington | Field expenses | 54.20 |
| 30 | 204 | Pay-roll (R. W. Goode) | Services, September, 1887 | 330.20 |
| 30 | 205 | Pay-roll (C. H. Fitch) | ......do | 360.40 |
| 30 | 206 | Pay-roll (R. H. Chapman) | ......do | 226.60 |
| 30 | 207 | Pay-roll (Frank Tweedy) | ......do | 340.40 |
| 30 | 208 | Pay-roll (E. M. Douglas) | ......do | 364.66 |
| 30 | 209 | Pay-roll (F. J. Knight) | ......do | 400.50 |
| 30 | 210 | Pay-roll (Eugene Ricksecker) | ......do | 306.99 |
| 30 | 211 | Pay-roll (H. S. Wallace) | ......do | 329.20 |
| 30 | 212 | Pay-roll (H. M. Wilson) | ......do | 305.20 |
| 30 | 213 | Pay-roll (A. F. Dunnington) | ......do | 215.00 |
| 30 | 214 | Pay-roll (R. H. McKee) | ......do | 277.80 |
| 30 | 215 | Ferdinand McCann | ......do | 22.50 |
| 30 | 216 | George W. McKee | Board and lodging | 25.00 |
| 30 | 217 | R. U. Goode | Field expenses | 65.65 |
| 30 | 218 | ......do | ......do | 40.15 |
| 30 | 219 | D. W. Spence | Services, September, 1887 | 50.00 |
| 30 | 220 | ......do | Board and lodging, August, 1887 | 31.00 |
| 30 | 221 | C. H. Fitch | Field expenses | 23.05 |
| 30 | 222 | E. M. Douglas | ......do | 35.50 |
| 30 | 223 | Zellhoefer & Noedel | Field subsistence, etc | 33.47 |
| 30 | 224 | A. W. Cleland | Field subsistence | 61.28 |
| 30 | 225 | William Ennis | ......do | 42.10 |
| 30 | 226 | Pay-roll (A. P. Davis) | Services, September, 1887 | 566.80 |
| 30 | 227 | Redick H. McKee | Field expenses | 21.18 |
| 30 | 228 | Mark B. Kerr | Services, September, 1887 | 146.80 |
| | | | | 22,982.93 |

*Abstract of disbursements made by P. H. Christie, special disbursing agent, U. S. Geological Survey, during the third quarter of* 1887.

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1887. | | | | |
| July 13 | 1 | Louis Nell | Traveling expenses | $36.50 |
| 13 | 2 | M. Hacket | ......do | 12.25 |
| 13 | 3 | Lewis J. Battle | ......do | 17.45 |
| 13 | 4 | W. L. Miller | ......do | 18.00 |
| 13 | 5 | R. Lee Longstreet | ......do | 4.05 |
| 13 | 6 | A. E. Murlin | ......do | 36.70 |
| 13 | 7 | Crawford & Fields | Forage of stock | 22.80 |
| 13 | 8 | Baker & Hall | Storage and supplies | 7.85 |
| 13 | 9 | Southern Express Company | Transportation of property | 12.25 |
| 13 | 10 | W. C. Edwards | Repairs on field material | 5.20 |
| 13 | 11 | M. Hackett | Miscellaneous field expenses | 41.85 |
| 13 | 12 | L. C. Fletcher | ......do | 108.73 |
| 13 | 13 | J. A. Stover | Material and supplies | 109.75 |
| 13 | 14 | S. H. Dent, jr | Traveling expenses | 10.60 |
| 13 | 15 | R. H. Jones & Sons | Repairs on field material | 52.65 |
| 13 | 16 | St. James Hotel | Subsistence | 31.25 |
| 13 | 17 | W. S. Hays | Field material | 32.70 |
| 15 | 18 | R. M. Towson | Traveling expenses | 14.20 |

*Abstract of disbursements made by P. H. Christie, etc.*—Continued.

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1887. | | | | |
| July 15 | 19 | R. McC. Michler | Traveling expenses | $35.00 |
| 15 | 20 | R. B. Cameron | ......do | 27.95 |
| 15 | 21 | Charles M. Yeates | ......do | 25.45 |
| 15 | 22 | John W. Emmert | ......do | 5.85 |
| 15 | 23 | Gaston Brown | ......do | 7.05 |
| 16 | 24 | A. E. Wilson | ......do | 12.55 |
| 16 | 25 | L. D. Brent | Miscellaneous field expenses | 29.80 |
| 16 | 26 | R. McC. Michler | ......do | 5.83 |
| 16 | 27 | A. J. Curd | Miscellaneous field supplies | 119.31 |
| 18 | 28 | V. Schoonmaker | Field material | 150.00 |
| 18 | 29 | L. C. Fletcher | Miscellaneous field expenses | 71.19 |
| 18 | 30 | Charles M. Yeates | ......do | 49.85 |
| 18 | 31 | N. A. Poole | Subsistence and supplies | 32.09 |
| 18 | 32 | E. C. Barnard | Miscellaneous field expenses | 67.23 |
| 18 | 33 | .....do | Traveling expenses | 10.25 |
| 18 | 34 | J. E. Kleindrist | ......do | 2.10 |
| 20 | 35 | N. B. Dunn | Forage of stock and expenses | 118.40 |
| 21 | 36 | L. C. Fletcher | Miscellaneous field expenses | 37.15 |
| 21 | 37 | ......do | ......do | 43.53 |
| 22 | 38 | W. S. Hays | Field material | 38.50 |
| 23 | 39 | .....do | ......do | 42.50 |
| 25 | 40 | R. H. Hooe | Services, July 1 to 9, 1 87, inclusive. | 14.67 |
| 25 | 41 | Gilbert Thompson | Traveling expenses | 36.15 |
| 25 | 42 | E. C. Barnard | Miscellaneous field expenses | 57.27 |
| 25 | 43 | W. S. Hays | Field material | 35.00 |
| 26 | 44 | Charles M. Yeates | Miscellaneous field expenses | 66.22 |
| 31 | 45 | J. W. Hays | Services, July, 1887 | 101.10 |
| 30 | 46 | R. Lee Longstreet | ......do | 84.20 |
| 31 | 47 | P. H. Christie | ......do | 151.60 |
| 30 | 48 | Pay-roll (Hackett) | .... do | 339.17 |
| 30 | 49 | Pay-roll (Barnard) | ......do | 331.24 |
| 30 | 50 | R. Lee Longstreet | Traveling expenses | 9.60 |
| 30 | 51 | Pay-roll (Fletcher) | Services, July, 1887 | 429.77 |
| 30 | 52 | Pay-roll (Nell) | ......do | 528.48 |
| 30 | 53 | Pay-roll (Yeates) | ......do | 585.14 |
| 30 | 54 | V. T. Carmichael | ......do | 17.74 |
| 31 | 55 | W. G. Cleland | ......do | 17.74 |
| 31 | 56 | John W. Carter | ......do | 20.96 |
| 31 | 57 | W T. Griswold | ......do | 151.60 |
| 30 | 58 | V. Schoomaker | Field material | 178.00 |
| 30 | 59 | Louis Nell | Miscellaneous field expenses | 37.50 |
| 30 | 60 | ......do | ......do | 89.10 |
| 30 | 61 | W. F. Fling | Forage of stock | 7.80 |
| 30 | 62 | Charles E. Cooke | Traveling expenses | 28.42 |
| 30 | 63 | George E. Kennedy & Son | Subsistence supplies | 164.86 |
| 30 | 64 | Pay-roll | Services, July, 1887 | 636.47 |
| Aug. 5 | 65 | Morris Bien | Miscellaneous field expenses | 49.25 |
| 5 | 66 | ......do | ......do | 255.37 |
| 5 | 67 | Charles M. Yeates | ......do | 71.95 |
| 6 | 68 | E. C. Barnard | ......do | 86.48 |
| 6 | 69 | J. W. Hays | ......do | 75.35 |
| 9 | 70 | M. Hackett | ......do | 125.46 |
| 10 | 71 | L. C. Fletcher | Traveling expenses | 8.50 |
| 10 | 72 | Henry W. Carpenter | ......do | 7.25 |
| 10 | 73 | L. C. Fletcher | Miscellaneous field expenses | 41.25 |
| 10 | 74 | ......do | ......do | 50.18 |
| 10 | 75 | P. H. Christie | Traveling expenses | 53.80 |
| 13 | 76 | Charles M. Yeates | Miscellaneous field expenses | 76.36 |
| 13 | 77 | L. C. Fletcher | ......do | 70.43 |
| 15 | 78 | P. H. Christie | ......do | 77.84 |
| 15 | 79 | R. Lee Longstreet | ......do | 26.47 |
| 16 | 80 | W. T. Griswold | ......do | 16.35 |
| 16 | 81 | ......do | Traveling expenses | 40.10 |
| 18 | 82 | S. J. Haislett | Field material | 70.00 |
| 18 | 83 | Louis Nell | Miscellaneous field expenses | 37.15 |
| 18 | 84 | ......do | ......do | 140.90 |
| 19 | 85 | E. C. Barnard | ......do | 65.68 |
| 19 | 86 | Morris Bien | ......do | 196.15 |
| 20 | 87 | L. C. Fletcher | ......do | 49.00 |
| 31 | 88 | ......do | ......do | 72.71 |
| 31 | 89 | Pay-roll | Services, August, 1887 | 596.60 |
| 31 | 90 | ......do | ......do | 355.30 |
| 31 | 91 | ......do | ......do | 541.40 |
| 31 | 92 | ......do | ......do | 351.90 |
| 31 | 93 | W. T. Griswold | ......do | 151.60 |
| 31 | 94 | J. W. Hays | ......do | 101.10 |
| 31 | 95 | R. Lee Longstreet | ......do | 84.20 |
| 31 | 96 | P. H. Christie | ......do | 151.60 |
| 31 | 97 | Pay-roll | ......do | 441.40 |

*Abstract of disbursements made by P. H. Christie, etc.*—Continued.

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1887. | | | | |
| Aug. 31 | 98 | J. W. Hays | Miscellaneous field expenses | $139.18 |
| 31 | 99 | Louis Nell | ......do | 122.50 |
| 31 | 100 | R. Lee Longstreet | ......do | 33.32 |
| 31 | 101 | Charles M. Yeates | ......do | 174.45 |
| 31 | 102 | W. T. Griswold | ......do | 43.20 |
| 31 | 103 | Gilbert Thompson | Traveling expenses | 83.66 |
| 31 | 104 | ......do | ......do | 38.40 |
| 31 | 105 | L. C. Fletcher | Miscellaneous field expenses | 54.36 |
| 31 | 106 | W. G. Cleland | Services, August 1 to 31, 1887 | 25.00 |
| 31 | 107 | John W. Carter | ......do | 25.00 |
| 31 | 108 | V. T. Carmichael | ......do | 25.00 |
| 31 | 109 | F. P. Fitzwilliam | Services, August 23 to 31, 1887, inclusive. | 7.25 |
| 31 | 110 | Pay-roll | Services, August, 1887 | 655.20 |
| Sept. 5 | 111 | Morris Bien | Miscellaneous field expenses | 83.38 |
| 5 | 112 | ......do | ......do | 150.47 |
| 7 | 113 | D. C. Harrison | Traveling expenses | 25.40 |
| 7 | 114 | M. Hackett | Miscellaneous field expenses | 159.31 |
| 8 | 115 | Charles M. Yeates | ......do | 111.92 |
| 8 | 116 | Louis Nell | ......do | 24.60 |
| 8 | 117 | ......do | ......do | 96.70 |
| 9 | 118 | L. C. Fletcher | ......do | 48.00 |
| 9 | 119 | E. C. Barnard | ......do | 119.70 |
| 10 | 120 | J. W. Hays | Traveling expenses | 19.00 |
| 10 | 121 | L. C. Fletcher | Miscellaneous field expenses | 89.70 |
| Aug. 31 | 122 | W. F. Fling | Forage of stock | 4.00 |
| Sept. 13 | 123 | L. C. Fletcher | Miscellaneous field expenses | 59.70 |
| 15 | 124 | R. O. Gordon | Traveling expenses | 13.85 |
| 17 | 125 | Louis Nell | Miscellaneous field expenses | 69.95 |
| 17 | 126 | ......do | ......do | 38.75 |
| 22 | 127 | Morris Bien | ......do | 127.60 |
| 23 | 128 | ......do | ......do | 39.20 |
| 23 | 129 | R. Lee Longstreet | ......do | 54.69 |
| 24 | 130 | J. W. Hays | ......do | 79.75 |
| 24 | 131 | E. C. Barnard | ......do | 123.60 |
| 24 | 132 | S. H. Dent, jr | Traveling expenses | 9.90 |
| 24 | 133 | Gilbert Thompson | ......do | 46.25 |
| 26 | 134 | L. C. Fletcher | Miscellaneous field expenses | 119.92 |
| 27 | 135 | Charles M. Yeates | ......do | 266.07 |
| 30 | 136 | R. C. McKinney | Services, September, 1887 | 97.80 |
| 30 | 137 | P. H. Christie | ......do | 146.80 |
| 30 | 138 | W. T. Griswold | ......do | 146.80 |
| 30 | 139 | R. Lee Longstreet | ......do | 81.60 |
| | 140 | Pay-roll | ......do | 432.20 |
| | 141 | ......do | ......do | 586.80 |
| | 142 | ......do | ......do | 346.20 |
| | 143 | ......do | ......do | 349.40 |
| | 144 | ......do | ......do | 532.20 |
| | 145 | ......do | ......do | 344.00 |
| 30 | 146 | D. C. Harrison | Miscellaneous field expenses | 10.10 |
| 30 | 147 | J. W. Hays | Services, September, 1887 | 97.80 |
| 30 | 148 | Desha Breckinridge | Traveling expenses | 28.60 |
| 30 | 149 | ......do | Services, September 1 to 10, 1887, inclusive. | 16.66 |
| 30 | 150 | Robert Breckenridge | ......do | 16.66 |
| 30 | 151 | E. S. Bodenheimer | Services, September 1 to 30, 1887, inclusive. | 12.00 |
| 30 | 152 | F. P. Fitzwilliam | ......do | 25.00 |
| 30 | 153 | W. G. Cleland | ......do | 25.00 |
| 30 | 154 | John W. Carter | ......do | 25.00 |
| 30 | 155 | V. T. Carmichael | ......do | 25.00 |
| 30 | 156 | R. O. Gordon | Miscellaneous field expenses | 53.13 |
| 30 | 157 | Louis Nell | ......do | 40.70 |
| 30 | 158 | ......do | ......do | 149.70 |
| 30 | 159 | D. C. Harrison | Services, September 1 to 30, 1887 | 97.80 |
| 30 | 160 | L. C. Fletcher | Miscellaneous field expenses | 66.78 |
| 30 | 161 | W. F. Fling | Forage of stock | 4.00 |
| 30 | 162 | Desha Breckenridge | Traveling expenses | 32.75 |
| 30 | 163 | R. C. McKinney | Miscellaneous field expenses | 8.88 |
| 30 | 164 | ......do | ......do | 31.13 |
| 30 | 165 | Morris Bien | ......do | 38.10 |
| 30 | 166 | ......do | ......do | 49.74 |
| | | | | 17,491.50 |

*Abstract of disbursements made by Arnold Hague, special disbursing agent, U. S. Geological Survey, during the third quarter of* 1887.

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1887. | | | | |
| Aug. 6 | 1 | George W. Wakefield | Animals | $450.00 |
| 6 | 2 | John Boyle | Tents | 48.20 |
| 29 | 3 | Eimer & Amend | Laboratory material | 17.15 |
| 29 | 4 | E. and H. T. Anthony & Co | Photographic material | 17.82 |
| 29 | 5 | Northern Pacific Express Company. | Expressage | 64.00 |
| Sept. 1 | 6 | Anton Karl | Traveling expenses | 26.75 |
| 1 | 7 | E. H. Shuster | ......do | 33.93 |
| 5 | 8 | A. Lamme & Co | Field subsistence | 245.30 |
| Aug. 30 | 9 | Pay-roll of employés | Salaries, July and August | 2,464.53 |
| Sept. 10 | 10 | George H. Arnholt | Services | 15.00 |
| 30 | 11 | Babcock & Miles | Field material | 8.75 |
| 30 | 12 | Arnold Hague | Traveling expenses | 13.75 |
| 30 | 13 | R. T. Smith | Field material | 35.90 |
| | | | | 3,441.08 |

*Abstract of disbursements made by A. O. D. Taylor, jr., special disbursing agent, U. S. Geological Survey, during the third quarter of* 1887.

| | | | | |
|---|---|---|---|---|
| 1887. | | | | |
| July 20 | 1 | H. L. Smyth | Traveling expenses | $9.33 |
| 20 | 2 | ......do | Field expenses | 5.25 |
| 20 | 3 | C. L. Whittle | Traveling expenses | 51.93 |
| 20 | 4 | ......do | Incidental expenses | 9.95 |
| 20 | 5 | F. E. Swift | Board bill to July 19, 1887 | 44.50 |
| 23 | 6 | T. Nelson Dale | Traveling expenses | 11.25 |
| 25 | 7 | H. L. Smyth | ......do | 10.96 |
| 26 | 8 | J. H. Flagg | Team hire | 21.50 |
| 27 | 9 | Lewis Brown, postmaster | Post-office box rent | 5.00 |
| 28 | 10 | W. R. Smyth | Traveling expenses | 7.57 |
| 28 | 11 | James McCormick | ......do | 4.73 |
| 29 | 12 | Edward Stabe | ......do | 5.95 |
| 29 | 13 | H. L. Smyth | Field expenses | 24.42 |
| 29 | 14 | Library Bureau | 3,000 catalogue cards | 7.80 |
| 30 | 15 | William H. Hobbs | Traveling expenses | 23.86 |
| Aug. 1 | 16 | Raphael Pumpelly | Pay for July, 1887 | 337.00 |
| 1 | 17 | A. O. D. Taylor, jr | ......do | 101.10 |
| July 31 | 18 | Pay-roll | ......do | 137.40 |
| Aug. 1 | 19 | T. Nelson Dale | Pay for July, 1887 | 150.00 |
| 1 | 20 | A. Prescott Baker | Rent for July, 1887 | 50.00 |
| 3 | 21 | J. Eliot Wolff | Pay for July, 1887 | 101.10 |
| 3 | 22 | C. L. Whittle | ......do | 50.00 |
| 5 | 23 | Raphael Pumpelly | Traveling expenses | 190.76 |
| 8 | 24 | T. Nelson Dale | ......do | 20.74 |
| 8 | 25 | William H. Hobbs | ......do | 20.78 |
| 9 | 26 | ......do | Pay for July. 1887 | 50.00 |
| 11 | 27 | H. L. Smyth | Traveling expenses | 7.30 |
| 11 | 28 | ......do | ......do | 8.23 |
| 11 | 29 | ......do | Board expenses of party | 46.16 |
| 17 | 30 | ......do | Field expenses | 24.46 |
| 18 | 31 | T. Nelson Dale | Traveling expenses | 8.89 |
| 18 | 32 | ......do | Four packing boxes | 1.25 |
| 23 | 33 | Raphael Pumpelly | Traveling expenses | 24.30 |
| 30 | 34 | J. Eliot Wolff | ......do | 58.25 |
| 31 | 35 | Raphael Pumpelly | Pay for August, 1887 | 337.00 |
| 31 | 36 | J. Eliot Wolff | ......do | 88.04 |
| 31 | 37 | T. Nelson Dale | ......do | 150.00 |
| 31 | 38 | William H. Hobbs | ......do | 50.00 |
| 31 | 39 | Pay-roll | August, 1887 | 214.20 |
| Sept. 7 | 40 | A. O. D. Taylor, jr | Pay for August, 1887 | 101.10 |
| 7 | 41 | T. Nelson Dale | Traveling expenses | 34.84 |
| 7 | 42 | C. L. Whittle | Pay for August, 1887 | 50.00 |
| 9 | 43 | S. Prescott Baker | Rent for August, 1887 | 50.00 |
| 9 | 44 | T. Nelson Dale | Traveling expenses | 36.49 |
| 12 | 45 | Raphael Pumpelly | ......do | 22.53 |
| 15 | 46 | Edward Stabe | Pay for September, 1887 | 23.33 |
| 15 | 47 | ......do | Traveling expenses | 5.55 |
| 21 | 48 | T. Nelson Dale | ......do | 13.96 |
| 23 | 49 | J. Eliot Wolff | ......do | 66.38 |
| 24 | 50 | William H. Hobbs | ......do | 52.34 |
| 24 | 51 | Ben. K. Emerson | Field expenses | 6.00 |
| 26 | 52 | Raphael Pumpelly | Traveling expenses | 39.50 |
| 27 | 53 | H. L. Smyth | Field expenses | 44.08 |
| 27 | 54 | ......do | ......do | 37.98 |
| 30 | 55 | William H. Hobbs | ......do | 6.87 |
| 30 | 56 | H. L. Smyth | Field subsistence | 37.66 |

*Abstract of disbursements made by A. O. D. Taylor, jr., etc.*—Continued

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1887. | | | | |
| Sept. 30 | 57 | Raphael Pumpelly | Pay for September, 1887 | $326.00 |
| 30 | 58 | J. Eliot Wolff | ......do | 55.43 |
| 30 | 59 | T. Nelson Dale | ......do | 150.00 |
| 30 | 60 | A. O. D. Taylor, jr | ......do | 97.80 |
| 30 | 61 | C. L. Whittle | ......do | 50.00 |
| 30 | 62 | William H. Hobbs | ......do | 50.00 |
| 30 | 63 | Pay-roll | Services, September, 1887 | 161.60 |
| 30 | 64 | A. Prescott Baker | Rent for September, 1887 | 50.00 |
| 30 | 65 | Henry Bull, jr | Telephone rent | 11.50 |
| 30 | 66 | Richard Bliss | Bibliographical work | 48.90 |
| 30 | 67 | J. F. Allison | Pay for September, 1887 | 38.65 |
| 30 | 68 | Raphael Pumpelly | Incidental expenses | 36.45 |
| | | | | 4,175.90 |

*Abstract of disbursements made by Fielding Burnes, disbursing agent, U. S. Geological Survey, during the third quarter of* 1887.

| | | | | |
|---|---|---|---|---|
| 1887. | | | | |
| Sept. 30 | 1 | J. H. Jennings | Services, September, 1887 | $81.60 |
| 30 | 2 | E. G. Kennedy | ......do | 50.00 |
| 30 | 3 | Lawrence Thompson | ......do | 81.60 |
| 30 | 4 | Charles E. Bassett | ......do | 81.60 |
| 30 | 5 | James Longstreet, jr | ......do | 49.00 |
| 30 | 6 | William H. Lovell | ......do | 81.60 |
| 30 | 7 | G. L. Johnson | ......do | 50.00 |
| 30 | 8 | E. B. Clark | ......do | 73.40 |
| 30 | 9 | W. E. Horton | ......do | 50.00 |
| 30 | 10 | Robert D. Cummin | ......do | 97.80 |
| 30 | 11 | Lawson Sandford | ......do | 50.00 |
| 30 | 12 | C. J. Akin | ......do | 60.00 |
| 30 | 13 | Sumner H. Bodfish | ......do | 163.00 |
| 30 | 14 | Pay-roll of employés | ......do | 1,011.20 |
| 30 | 15 | Marcus Baker | Traveling expenses | 89.01 |
| 30 | 16 | ......do | Maps | 10.50 |
| | | | | 2,080.31 |

*Abstract of disbursements made by R. R. Hawkins, special disbursing agent, U. S. Geological Survey, during the third quarter of* 1887.

| | | | | |
|---|---|---|---|---|
| 1887. | | | | |
| July 30 | 1 | Pay-roll | Services, July, 1887 | $591.30 |
| 30 | 2 | Albion S. Howe | ......do | 60.00 |
| 30 | 3 | Frank Rader | ......do | 30.00 |
| 30 | 4 | Charles McLaren | ......do | 65.00 |
| Aug. 1 | 5 | H. W. Turner | Field expenditures | 48.29 |
| 4 | 6 | W. Lindgren | ......do | 57.73 |
| 8 | 7 | F. C. Boyce | Services, July, 1887 | 60.00 |
| 8 | 8 | I. W. Denel | ......do | 40.00 |
| 8 | 9 | Main & Winchester | Supplies | 29.25 |
| 8 | 10 | S. Leitz & Co | Repairs | 12.00 |
| 8 | 11 | H. L. Howse | Supplies | 10.00 |
| 11 | 12 | Sam. C. Partridge | ......do | 6.35 |
| 11 | 13 | William B. Ross | Blacksmithing | 9.00 |
| 11 | 14 | A. Carlisle & Co | Supplies | 21.35 |
| 25 | 15 | Frank Barnard & Co | Fuel | 3.50 |
| 25 | 16 | Main & Winchester | Supplies and repairs | 32.75 |
| 31 | 17 | F. C. Boyce | Services, August, 1887 | 60.00 |
| 31 | 18 | I. W. Denel | ......do | 40.00 |
| 31 | 19 | Pay-roll | ......do | 591.30 |
| 31 | 20 | Albion S. Howe | ......do | 60.00 |
| 31 | 21 | G. W. Grannis | Rent of rooms | 105.32 |
| Sept. 2 | 22 | W. Lindgren | Traveling expenses | 70.05 |
| 3 | 23 | H. W. Turner | Field expenditures | 44.46 |
| 3 | 24 | ......do | Traveling expenses | 32.95 |
| 3 | 25 | Charles McLaren | Services, August, 1887 | 65.00 |
| 3 | 26 | Frank Rader | ......do | 30.00 |
| 7 | 27 | W. Lindgren | Field expenditures | 77.72 |
| 9 | 28 | I. R. Robinson | Horse | 65.00 |
| 14 | 29 | I. W. Denel | Services, September 1 to 15, 1887 | 20.00 |
| 15 | 30 | Abner Doble | Supplies and repairs | 12.25 |
| 15 | 31 | Main & Winchester | ......do | 8.25 |

*Abstract of disbursements made by R. R. Hawkins, etc.*—Continued.

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1887. | | | | |
| Sept. 15 | 32 | I. I. Vasconcellos | Supplies and repairs | $13.50 |
| 15 | 33 | H. L. Howse | ......do | 4.45 |
| 17 | 34 | A. C. Klinkner & Co | Supplies | 9.60 |
| 15 | 35 | Elias Field | Supplies and foraging public animals. | 29.60 |
| 17 | 36 | H. W. Turner | Field supplies | 23.22 |
| 17 | 37 | W. Lindgren | Field expenditures | 54.04 |
| 17 | 38 | ....do | Traveling expenses | 20.00 |
| 28 | 39 | Goldberg, Bowen & Co | Field supplies | 135.09 |
| 28 | 40 | ......do | ......do | 73.75 |
| 30 | 41 | Charles McLaren | Services, September, 1887 | 65.00 |
| 30 | 42 | Frank Rader | ......do | 30.00 |
| 30 | 43 | Pay-roll | ......do | 572.40 |
| 30 | 44 | Albion S. Howe | ......do | 60.00 |
| 30 | 45 | F. C. Boyce | ......do | 60.00 |
| 30 | 46 | R. R. Hawkins | Cash expenditures | 32.20 |
| | | | | 3,541.67 |

*Abstract of disbursements made by Alfred M. Rogers, disbursing agent, U. S. Geological Survey, during the third quarter of* 1887.

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1887. | | | | |
| July 25 | 1 | Richard Beales | Field supplies and expenses | $20.00 |
| Aug. 8 | 2 | A. J. Bedell | Services, July 24 to 27, 1887, inclusive. | 20.00 |
| July 31 | 3 | Pay-roll | Services, July, 1887 | 704.22 |
| Aug. 12 | 4 | W. H. Hyatt | Field supplies and expenses | 23.00 |
| 12 | 5 | John Murphy | ......do | 5.25 |
| 12 | 6 | J. H. Smith | Services | 6.00 |
| 12 | 7 | W. L. Patten & Co | Field supplies and expenses | 8.00 |
| 12 | 8 | Roberts Hardware Company | Field material | 16.80 |
| 25 | 9 | Daniels & Fisher | Field supplies | 3.75 |
| 31 | 10 | Pay-roll | Services, August, 1887 | 730.70 |
| Sept. 19 | 11 | A. Ganthier & Co | Services | 2.25 |
| 30 | 12 | Peter McCourt | Rent | 150.00 |
| 30 | 13 | R. M. Davis | Photographic material | 22.68 |
| 30 | 14 | S. F. Emmons | Pay | 1,000.00 |
| 30 | 15 | Chain, Hardy & Co | Stationery | 2.85 |
| 30 | 16 | Denver Fire Clay Company | Laboratory material | 7.00 |
| 30 | 17 | W. H. Laurence & Co | Stationery | 5.64 |
| 30 | 18 | Kerstins, Peters & Co | Office supplies | 3.60 |
| 30 | 19 | H. Z. Solomon | Field subsistence | 28.30 |
| 30 | 20 | Pay-roll | September, 1887 | 708.60 |
| 30 | 21 | Sam. P. Barbee | Rent, etc | 161.30 |
| 30 | 22 | E. H. Hill | Ranching stock and field supplies | 76.00 |
| 30 | 23 | S. F. Emmons | Traveling expenses | 66.25 |
| 30 | 24 | Denver and Rio Grande Railroad Company. | Transportation of property | 108.27 |
| 30 | 25 | S. F. Emmons | Traveling expenses | 119.01 |
| 30 | 26 | Denver and Rio Grande Railroad Express. | Transportation of property | 14.65 |
| 30 | 27 | John Moncrieff | Services | 1.00 |
| 30 | 28 | Dan Phillips | ......do | 26.70 |
| 30 | 29 | Western Union Telegraph Company. | Correspondence | .40 |
| 30 | 30 | Pacific Express Company | Transportation of property | 1.25 |
| 30 | 31 | R. W. Speer, postmaster | Correspondence | 2.50 |
| | | | | 4,045.97 |

*Abstract of disbursements made by Jno H. Renshawe, special disbursing agent, U. S. Geological Survey, during the third quarter of* 1887.

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1887 | | | | |
| July 20 | 1 | C. T. Reid | Traveling expenses | $5.25 |
| 26 | 2 | D. A. Munger | Hotel bill | 40.64 |
| 20 | 3 | C. T. Reid | Traveling expenses | 17.50 |
| 26 | 4 | William J. Peters | ......do | 17.50 |
| 26 | 5 | ......do | ......do | 5.25 |
| 26 | 6 | John H. Renshawe | ......do | 12.25 |
| 27 | 7 | H. L. Baldwin, jr | ......do | 81.25 |
| 27 | 8 | C. W. Hawkins | ......do | 32.75 |
| 27 | 9 | William H. Herron | ......do | 90.25 |
| Aug. 13 | 10 | George Unsell | Services, July 4–31, 1887, inclusive | 31.61 |

*Abstract of disbursements made by Jno. H. Renshawe, etc.*—Continued.

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1887. | | | | |
| July 27 | 11 | H. L. Baldwin, jr | Field expenses | $163.95 |
| 31 | 12 | Pay-roll, July | Services | 463.06 |
| 30 | 13 | Van H. Manning, jr | Traveling expenses | 17.40 |
| 30 | 14 | S. S. Gannett | ......do | 16.80 |
| 30 | 15 | W. E. Lackland | ......do | 14.30 |
| 30 | 16 | Basil Duke | ......do | 14.55 |
| 30 | 17 | George T. Hawkins | ......do | 52.35 |
| 30 | 18 | Teller & Marghardt | Subsistence | 230.26 |
| 30 | 19 | S. S. Gannett | Field expenses | 136.42 |
| Aug. 1 | 20 | Charles Hall | Freight charges | 156.00 |
| 6 | 21 | S. S. Gannett | Field expenses | 112.95 |
| 13 | 22 | John H. Renshawe | ......do | 59.53 |
| 13 | 23 | ......do | Traveling expenses | 76.50 |
| 13 | 24 | C. T. Reid | ......do | 6.04 |
| 13 | 25 | H. B. Blair | ......do | 18.40 |
| 13 | 26 | J. A. Doyle | Services | 3.23 |
| 13 | 27 | Mrs. I. P. Powell | ......do | 20.97 |
| 13 | 28 | William J. Peters | ......do | 101.10 |
| 13 | 29 | J. H. Hagerty | ......do | 35.00 |
| 13 | 30 | William H. Herron | ......do | 60.60 |
| 13 | 31 | Foster & Hess | Hire of horse and wagon | 31.00 |
| 13 | 32 | H. B. Blair | Field expenses | 28.35 |
| 13 | 33 | H. L. Baldwin, jr | ......do | 103.89 |
| 25 | 34 | S. S. Gannett | ......do | 128.95 |
| 25 | 35 | D. A. Munger | Hotel bill | 88.65 |
| 25 | 36 | H. L. Baldwin, jr | Field expenses | 59.59 |
| 26 | 37 | ......do | ......do | 28.10 |
| July 30 | 38 | Basil Duke | Services, July 1 to 21, 1887 | 50.00 |
| 30 | 39 | W. E. Lackland | ......do | 50.00 |
| Aug. 27 | 40 | Foster & Hess | Hire of horse and wagon | 22.00 |
| 31 | 41 | John H. Renshawe | Services, August 1-31, 1887 | 210.60 |
| Sept. 1 | 42 | William J. Peters | ......do | 101.10 |
| 1 | 43 | C. T. Reid | ......do | 100.00 |
| Aug. 31 | 44 | Pay-roll | Services, August and July, 1887 | 466.40 |
| 31 | 45 | ......do | Services, August, 1887 | 355.80 |
| 31 | 46 | ......do | ......do | 232.90 |
| Sept. 9 | 47 | Van H. Manning, jr | Services, July 1 to August 31, 1887 | 141.60 |
| 17 | 48 | John H. Renshawe | Traveling expenses | 80.45 |
| 17 | 49 | ......do | Field expenses | 42.11 |
| 26 | 50 | Foster & Hess | Hire of horse and wagon | 44.50 |
| 30 | 51 | D. A. Munger | Hotel bill | 84.12 |
| 30 | 52 | John H. Renshawe | Services | 203.80 |
| 29 | 53 | H. H. Lee | ......do | 25.00 |
| | | | | 4,772.57 |

*Abstract of disbursements made by G. K. Gilbert, disbursing agent, U. S. Geological Survey, during the third quarter of* 1887.

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1887. | | | | |
| July 30 | 1 | G. K. Gilbert | Services, July, 1887 | $337.00 |
| Aug. 31 | 2 | ......do | Services, August, 1887 | 337.00 |
| Sept. 30 | 3 | ......do | Traveling expenses | 27.69 |
| 30 | 4 | ......do | ......do | 75.44 |
| 30 | 5 | ......do | Servic s, September, 1887 | 326.00 |
| | | | | 1,103.13 |

*Abstract of disbursements made by Jno. D. McChesney, chief disbursing clerk, U. S Geological Survey, during the fourth quarter of* 1887.

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1887. | | | | |
| Oct. 6 | 1 | Columbus Freeman | Services, October 1 to 6, 1887 | $6.77 |
| 6 | 2 | ......do | Traveling expenses | 15.70 |
| 7 | 3 | Hermann Baumgarten | Office furniture | .50 |
| 7 | 4 | Pay-roll of employes | Services, September, 1887 | 576.94 |
| 11 | 5 | E. H. Barbour | Services, July, August, and September, 1887. | 400.00 |
| 11 | 6 | Fred. Brown | Services, September, 1887 | 90.00 |
| 11 | 7 | Collier Cobb | ......do | 50.00 |
| 11 | 8 | R. S. Tarr | ......do | 50.00 |

*Abstract of disbursements made by Jno. D. McChesney, etc.*—Continued.

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1887. | | | | |
| Oct. 11 | 9 | N. S. Shaler | Services, September, 1887 | $260.00 |
| 11 | 10 | Thomas C. Howie | ......do | 49.83 |
| 11 | 11 | Atchison, Topeka and Sante Fé Railroad. | Transportation of assistants | 73.50 |
| 11 | 12 | Pennsylvania Railroad Company. | ......do | 35.00 |
| 11 | 13 | F. A. Green & Co | Field subsistence | 3.20 |
| 11 | 14 | A. Lamme & Co | ......do | 44.42 |
| 11 | 15 | ......do | Field supplies | 9.81 |
| 11 | 16 | Wm. J. Park & Co | Stationery and drawing material | 12.58 |
| 11 | 17 | Ira Sayles | Traveling expenses | 49.94 |
| 11 | 18 | Wyckoff, Seamans & Benedict | Remodeling 2 typewriters | 70.00 |
| 12 | 19 | John F, Stephenson | Freight charges and hauling | 2.70 |
| 12 | 20 | Charles Oley | Services, September 1 to 20, 1887 | 60.00 |
| 12 | 21 | ......do | Services, September 21 to 28, 1887 | 28.00 |
| 12 | 22 | C. R. Van Hise | ......do | 80.00 |
| 12 | 23 | W. S. Bayley | ......do | 60.00 |
| 12 | 24 | J. S. Newberry | Services, September 1 to October 3, 1887. | 322.75 |
| 12 | 25 | National Press and Intelligence Company. | Newspaper clippings | 9.05 |
| 12 | 26 | J. Judell | Services | 127.49 |
| 12 | 27 | ......do | Field and subsistence supplies | 97.81 |
| 12 | 28 | Zellhoefer and Noedel | 1 horse | 80.00 |
| 12 | 29 | J. B. Block | Field and subsistence supplies | 62.60 |
| 12 | 30 | F. G. Pratt & Co | Subsistence supplies | 77.68 |
| 14 | 31 | Julius Baumgarten | Office furniture | 3.00 |
| 17 | 32 | Old Colony Railroad Company | Transportation of assistants | 21.50 |
| 17 | 33 | Saint Joseph and Grand Island Railroad. | ......do | 2.10 |
| 17 | 34 | Terre Haute and Indianapolis Railroad. | ......do | 40.50 |
| 17 | 35 | S. J. Haislett | 1 canvas cover | 3.50 |
| 17 | 36 | Great Falls Ice Company | Ice for July, August, and September, 1887. | 50.77 |
| 17 | 37 | M. P. Felch | Services, September, 1887 | 190.00 |
| 17 | 38 | Roland D. Irving | Traveling expenses | 163.29 |
| 17 | 39 | Nelson H. Darton | ......do | 89.32 |
| 17 | 40 | ......do | ......do | 85.70 |
| 18 | 41 | Edward Kubel | Material for repairs to instruments. | 15.33 |
| 18 | 42 | Mutual District Messenger Company. | Rental of night watch | 5.40 |
| 18 | 43 | George H. Williams | Services, July 1 to October 1, 1887 | 225.00 |
| 18 | 44 | Lee Lesquereux | Services, August and September, 1887. | 150.00 |
| 18 | 45 | W. N. Merriam | Services, September, 1887 | 114.20 |
| 19 | 46 | Subsistence Department U. S. Army. | Subsistence supplies | 51.51 |
| 19 | 47 | Frank H. Atkins | ......do | 82.94 |
| 19 | 48 | W. S. Bayley | Traveling expenses | 30.80 |
| 20 | 49 | W. H. Dall | ......do | 23.80 |
| 20 | 50 | Chicago and Alton Railroad Company. | Transportation of assistants | 126.95 |
| 20 | 51 | P. H. Bevier | Traveling expenses | 110.03 |
| 20 | 52 | W. H. Luster, jr | ......do | 25.33 |
| 20 | 53 | Asher Atkinson | ......do | 52.62 |
| 20 | 54 | C. C. Vermeule | ......do | 21.95 |
| 20 | 55 | Lawrence C. Johnson | ......do | 92.60 |
| 20 | 56 | C. C. Vermeule | Miscellaneous field expenses | 18.30 |
| 20 | 57 | Subsistence Department U. S. Army. | Subsistence supplies | 29.92 |
| 21 | 58 | Collier Cobb | Traveling expenses | 57.41 |
| 21 | 59 | F. W. Bennett | ......do | 92.06 |
| 21 | 60 | P. D. Staats | ......do | 41.50 |
| 21 | 61 | C. C. Jones | ......do | 5.25 |
| 22 | 62 | Henry Gannett | ......do | 143.03 |
| 22 | 63 | John McDermott & Bros | Repairs to public wagon | 45 00 |
| 24 | 64 | S. J. Galbraith | Services, July 19 to 20, 1887 | 5.00 |
| 24 | 65 | ......do | Traveling expenses | 10.55 |
| 25 | 66 | Gottlieb Spitzer | Office furniture and repairs | 3.90 |
| 25 | 67 | S. D. Howie | Services, September 1 to October 11, 1887. | 149.03 |
| 26 | 68 | J. E. Todd | Services, September, 1887 | 40.00 |
| 26 | 69 | Warren Upham | Services, July 1 to September 30, 1887. | 300.00 |
| 26 | 70 | Jos. Gaujon | Services, August 29 to October 3, 1887. | 72.00 |
| 26 | 71 | W. M. York | Services, August 29 to October 1, 1887. | 68.00 |
| 26 | 72 | W. N. Merriam | Traveling expenses | 182.97 |

*Abstract of disbursements made by Jno. D. McChesney, etc.*—Continued.

| Date. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1887. | | | | |
| Oct. 26 | 73 | C. R. Van Hise | Traveling expenses | $50.91 |
| 26 | 74 | L. C. Wooster | ......do | 81.24 |
| 26 | 75 | R. S. Tarr | ......do | 132.68 |
| 26 | 76 | Bailey Willis | ......do | 19.25 |
| 26 | 77 | N. S. Shaler | ......do | 343.49 |
| 26 | 78 | J. Korber & Co | Repairs to field material | 43.25 |
| 27 | 79 | Bailey Willis | Field expenses | 110.29 |
| 27 | 80 | Albert Williams | Services, July 20 to August 4, 1887 | 75.00 |
| 27 | 81 | P. C. Warman | Traveling expenses | 41.00 |
| 27 | 82 | Atlantic and Pacific Railroad | Transportation of assistants | 97.80 |
| 29 | 83 | A. C. Peale | Traveling expenses | 110.60 |
| 31 | 84 | Ira Sayles | Services, October, 1887 | 117.90 |
| 31 | 85 | Leo Lesquereux | ......do | 75.00 |
| 31 | 86 | J. Henry Blake | ......do | 151.60 |
| 31 | 87 | H. R. Geiger | ......do | 126.40 |
| 31 | 88 | F. W. Geiger | ......do | 45.00 |
| 31 | 89 | Sam H. Scudder | ......do | 210.60 |
| 31 | 90 | Charles D. Walcott | ......do | 168.50 |
| 31 | 91 | Lawrence C. Johnson | ......do | 117.90 |
| 31 | 92 | Robert T. Hill | ......do | 101.10 |
| 31 | 93 | William M. Fontaine | ......do | 168.50 |
| 31 | 94 | Roland D. Irving | ......do | 252.70 |
| 31 | 95 | W. N. Merriam | ......do | 117.90 |
| 31 | 96 | W. S. Bayley | ......do | 60.00 |
| 31 | 97 | O. C. Marsh | ......do | 337.00 |
| 31 | 98 | G. Baur | ......do | 140.00 |
| 31 | 99 | F. Berger | ......do | 70.00 |
| 31 | 100 | H. Gibb | ......do | 60.00 |
| 31 | 101 | L. P. Bush | ......do | 50.00 |
| 31 | 102 | Robert E. C. Stearns | ......do | 168.50 |
| 31 | 103 | G. F. Becker | ......do | 337.00 |
| 31 | 104 | Pay-roll of employés | ......do | 2,200.20 |
| 31 | 105 | ......do | ......do | 3,211.90 |
| 31 | 106 | ......do | ......do | 773.30 |
| 31 | 107 | ......do | ......do | 3,060.80 |
| 31 | 108 | ......do | ......do | 390.7 |
| 31 | 109 | George W. Shutt | ......do | 252.70 |
| Nov. 1 | 110 | Quartermaster's Department, U. S. Army. | Forage | 15.73 |
| 2 | 111 | N. S. Shaler | Services, October, 1887 | 260.00 |
| 1 | 112 | Northern Pacific Railroad | Transportation of assistants | 60.00 |
| 1 | 113 | Jos. D. Weeks | Services | 500.00 |
| 1 | 114 | Frank Leverett | Services, July 1 to October 13, 1887 | 450.00 |
| 1 | 115 | Washington Gas-Light Company | Gas, October, 1887 | 73.26 |
| 2 | 116 | Arthur Keith | Services, October, 1887 | 50.00 |
| 2 | 117 | ......do | Traveling expenses | 21.75 |
| 2 | 118 | C. W. Hayes | Services, October, 1887 | 50.00 |
| 2 | 119 | James G. Bowen | Care and forage of public animals | 80.67 |
| 2 | 120 | Nelson H. Darton | Traveling expenses | 45.25 |
| 2 | 121 | ......do | ......do | 23.12 |
| 2 | 122 | E. E. Barnes | Services, August, 1887 | 50.50 |
| 3 | 123 | Lottie M. Schmidt | Services, October, 1887 | 52.00 |
| 3 | 124 | Lester F. Ward | Miscellaneous field expenses | 105.92 |
| 3 | 125 | ......do | Traveling expenses | 57.75 |
| 3 | 126 | R. C. Jones | Publications | 7.25 |
| 3 | 127 | W. S. Bayley | Traveling expenses | 149.29 |
| 3 | 128 | H. R. Geiger | ......do | 83.45 |
| 3 | 129 | Joseph F. Page | Florence oil-stove cover | 3.00 |
| 4 | 130 | D. L. Samnns | Forage | 26.80 |
| 4 | 131 | J. E. Todd | Traveling expenses | 205.29 |
| 4 | 132 | F. W. Bennett | ......do | 40.10 |
| 4 | 133 | J. B. Reynolds | ......do | 28.79 |
| 4 | 134 | Asher Atkinson | ......do | 21.26 |
| 3 | 135 | John D. Black | ......do | 46.40 |
| 3 | 136 | ......do | ......do | 28.60 |
| 5 | 137 | John R. Proctor | Services, September 1 to November 1, 1887. | 120.00 |
| 5 | 138 | Charles S. Cudlip | Photographic supplies | 39.25 |
| 5 | 139 | Western Union Telegraph Company. | Telegrams | 6.94 |
| 5 | 140 | George W. Cook | Traveling expenses | 51.81 |
| 7 | 141 | Lawrence C. Johnson | ......do | 41.15 |
| 7 | 142 | Denver and Rio Grande Western Railroad. | Transportation of assistants | 40.60 |
| 7 | 143 | John B. Bean | Hire of transportation | 429.00 |
| 7 | 144 | Spencer & Brown | Repairs | 21.00 |
| 7 | 145 | August F. Foerste | Services, July 15 to September 30, 1887. | 75.00 |

*Abstract of disbursements made by Jno. D. McChesney, etc.*—Continued.

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1887. Nov. 7 | 146 | Baltimore and Ohio Telegraph Company. | Telegrams | $0.58 |
| 8 | 147 | Summer & Morris | Field material | 2.20 |
| 8 | 148 | Zellhoefer & Noedel | Miscellaneous field expenses | 108.80 |
| 8 | 149 | John B. Bean | Hire of field transportation | 387.75 |
| 8 | 150 | Jesse W. Lyman | Services, August 2 to September 17, 1887 | 70.50 |
| 8 | 151 | Samuel L. Penfield | Services, July 23 to October 5, 1887 | 320.00 |
| 8 | 152 | C. R. Van Hise | Services, October, 1887 | 85.00 |
| 8 | 153 | William D. Heistand | Services, October 17-31, 1887 | 22.58 |
| 8 | 154 | Pay-roll of employés | Services, October, 1887 | 359.09 |
| 8 | 155 | Ira Sayls | Traveling expenses | 96.28 |
| 9 | 156 | I. M. Buell | Services, July 2 to September 2, 1887 | 140.00 |
| 9 | 157 | Tallman & McFadden | Laboratory material and supplies | 19.13 |
| 9 | 158 | Chicago and Alton Railroad | Transportation of assistants | 14.50 |
| 9 | 159 | Denver and Rio Grande Railroad | do | 9.69 |
| 9 | 160 | Ohio and Mississippi Railway | do | 20.25 |
| 9 | 161 | E. H. King | Office furniture | 76.00 |
| 9 | 162 | Royce & Marean | do | 6.00 |
| 9 | 163 | Fitz D. Ermantrout | Traveling expenses | 28.95 |
| 10 | 164 | E. Shaw | do | 48.30 |
| 10 | 165 | Henry J. Green | Instruments and repairs | 580.09 |
| 10 | 166 | W. & L. E. Gurley | do | 516.40 |
| 10 | 167 | Fred. A. Schmidt | Artists' material | 1.08 |
| 10 | 168 | John F. Paret | Office and field supplies | 12.20 |
| 10 | 169 | American Tool and Machine Company. | Laboratory material | 21.22 |
| 10 | 170 | W. N. Merriam | Traveling expenses | 157.42 |
| 10 | 171 | Mutual District Messenger Company. | Rental of night watch | 5.00 |
| 11 | 172 | Cooke & Co | Laboratory supplies | 10.65 |
| 11 | 173 | Oregon and California Railroad | Transportation of assistants | 27.36 |
| 11 | 174 | Baltimore and Potomac Railroad | do | 5.00 |
| 11 | 175 | Chicago, Milwaukee and St. Paul Railroad. | do | 12.50 |
| 11 | 176 | Eimer & Amend | Laboratory material and supplies | 211.19 |
| 11 | 177 | James W. Queen & Co | Instruments, etc | 179.53 |
| 12 | 178 | Robert E. C. Stearns | Traveling expenses | 69.69 |
| 14 | 179 | George H. Williams | do | 53.11 |
| 14 | 180 | do | Pay, October 10 to November 1, 1887 | 35.00 |
| 14 | 181 | Baltimore and Ohio Railroad | Transportation of assistants | 74.60 |
| 15 | 182 | L. H. Schneider's Son | Miscellaneous field and office supplies. | 36.62 |
| 15 | 183 | David T. Day | Traveling expenses | 40.65 |
| 15 | 184 | Chicago, St. Paul, Minneapolis and Omaha Railway. | Transportation of assistants | 29.00 |
| 15 | 185 | Charles S. Cudlip | Photographic supplies | 56.25 |
| 16 | 186 | Frank Sutton | Services, October, 1887 | 75.80 |
| 16 | 187 | L. B. Putney | Forage for public animals | 58.31 |
| 16 | 188 | Adams Express Company | Freight charges | 310.08 |
| 19 | 189 | C. H. Kraft | Laboratory supplies | 59.22 |
| 21 | 190 | H. R. Geiger | Traveling expenses | 129.56 |
| 21 | 191 | Charles D. Walcott | do | 399.00 |
| 21 | 192 | Aug. F. Foerste | do | 64.27 |
| 21 | 193 | Chicago and Northwestern Railroad. | Transportation of assistants | 24.50 |
| 21 | 194 | Burlington and Missouri River Railroad in Nebraska. | do | 36.05 |
| 21 | 195 | M. P. Felch | Services, October 1 to 31, 1887 | 190.00 |
| 21 | 196 | B. F. McCanlly & Co | Care and forage of public animals | 16.25 |
| 21 | 197 | Baltimore and Ohio Railroad | Freight charges | 10.15 |
| 21 | 198 | George W. Knox | do | 46.67 |
| 21 | 199 | Barney Boberg | Services, October, 1887 | 50.00 |
| 21 | 200 | Harry Montgomery | do | 50.00 |
| 21 | 201 | Joseph I. Clawson | do | 60.00 |
| 21 | 202 | Jere Hatch | do | 50.00 |
| 22 | 203 | George Cartner | Publications | 7.00 |
| 22 | 204 | Frank Burns | Traveling expenses | 55.04 |
| 22 | 205 | A. C. Peale | Field expenses, July 14 to October 1, 1887. | 152.93 |
| 23 | 206 | Hensel, Buckmann & Lorbacher. | Freight charges | 17.21 |
| 23 | 207 | Robert Boyd | Supplies, repairs, etc | 95.34 |
| 23 | 208 | H. R. Geiger | Traveling expenses | 4.25 |
| 23 | 209 | Edw. T. Seynave, secretary | Publications | 5.00 |
| 23 | 210 | Ivison, Blakeman & Co | 1 arm bracket | 1.50 |
| 23 | 211 | J. F. Bruce & Bro | Field material | 15.00 |
| 23 | 212 | Quartermaster's Department, U. S. Army. | Post flag | 10.20 |
| 25 | 213 | Frederick W. Taylor | Services, October 1 to November 25, 1887. | 20.00 |

*Abstract of disbursements made by Jno. D. McChesney, etc.*—Continued.

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1887. | | | | |
| Nov. 25 | 214 | C. A. White | Traveling expenses | $203.41 |
| 25 | 215 | C. B. Boyle | ......do | 106.60 |
| 25 | 216 | Ira M. Buell | ......do | 24.77 |
| 25 | 217 | Northern Pacific Railroad | Transportation of assistants | 441.95 |
| 25 | 218 | Western Union Telegraph Company. | Telegrams | 8.03 |
| 30 | 219 | Emil Greiner | Laboratory material | 24.25 |
| 30 | 220 | J. Bishop & Co | ......do | 39.60 |
| 30 | 221 | John F. Stephenson | Freight charges and hauling | 5.12 |
| 30 | 222 | Lawrence C. Johnson | Services, November, 1887 | 114.20 |
| 30 | 223 | William M. Fontaine | ......do | 163.00 |
| 30 | 224 | Roland D. Irving | ......do | 244.60 |
| 30 | 225 | Robert T. Hill | ......do | 97.80 |
| 30 | 226 | Leo Lesquereux | ......do | 75.00 |
| 30 | 227 | Sam. H. Scudder | ......do | 203.80 |
| 30 | 228 | O. C. Marsh | ......do | 326.00 |
| 30 | 229 | E. H. Barbour | ......do | 265.20 |
| 30 | 230 | G. Baur | ......do | 140.00 |
| 30 | 231 | Fred. Brown | ......do | 90.00 |
| 30 | 232 | F. Berger | ......do | 70.00 |
| 30 | 233 | Hugh Gibb | ......do | 60.00 |
| 30 | 234 | L. P. Bush | ......do | 50.00 |
| 30 | 235 | Arthur Keith | ......do | 50.00 |
| 30 | 236 | Minnesota and Northwestern Railroad. | Transportation of assistants | 29.00 |
| 30 | 237 | E. E. Jackson & Co | Lumber, etc | 139.83 |
| 30 | 238 | Buffalo Dental Manufacturing Company. | Laboratory material | 3.75 |
| 30 | 239 | Pay-roll of employés | Services, November, 1887 | 2,979.40 |
| 30 | 240 | ......do | ......do | 748.40 |
| 30 | 241 | ......do | ......do | 3,178.97 |
| 30 | 242 | ......do | ......do | 4,146.40 |
| 30 | 243 | ......do | ......do | 443.40 |
| 30 | 244 | ......do | ......do | 244.60 |
| Dec. 1 | 245 | F. W. Geiger | ......do | 45.00 |
| 1 | 246 | W. S. Bayley | ......do | 60.00 |
| 1 | 247 | W. N. Merriam | ......do | 114.20 |
| 1 | 248 | William D. Heistand | Services between November 1 and 30, 1887. | 50.00 |
| 1 | 249 | Pay-roll of employés | Services, November, 1887 | 274.80 |
| 2 | 250 | Z. D. Gilman | Photographic and laboratory supplies. | 214.12 |
| 2 | 251 | ......do | Laboratory supplies | 16.74 |
| 2 | 252 | J. Henry Blake | Services, November, 1887 | 146.80 |
| 2 | 253 | N. S. Shaler | ......do | 260.00 |
| 2 | 254 | Washington Gas-Light Company. | Gas | 90.40 |
| 2 | 255 | James G. Bowen | Care of public animals | 70.75 |
| 2 | 256 | B. F. McCaully & Co | ......do | 24.50 |
| 3 | 257 | C. R. Van Hise | Services, November, 1887 | 70.00 |
| 5 | 258 | John F. Paret | Drawing material | 11.30 |
| 5 | 259 | Richmond and Danville Railroad. | Transportation of assistants | 555.50 |
| 6 | 260 | A. H. Robbins | Traveling expenses | 8.25 |
| 6 | 261 | Barney Boberg | Services, November, 1887 | 50.00 |
| 6 | 262 | Joseph I. Clawson | ......do | 60.00 |
| 6 | 263 | Jere Hatch | ......do | 50.00 |
| 6 | 264 | Frank Sutton | ......do | 73.40 |
| 6 | 265 | William P. Rust | Services, October 1 to November 30, 1887. | 169.00 |
| 6 | 266 | Oscar W. Tefft | Services, October and November, 1887. | 10.00 |
| 6 | 267 | Gaston A. Douglass & Co | Photographic material | 3.70 |
| 6 | 268 | Eimer & Amend | Laboratory material and supplies | 257.22 |
| 7 | 269 | Easton & Rupp | Office supplies | 1.35 |
| 7 | 270 | Warren Upham | Salary, October 1 to November 30, 1887. | 198.90 |
| 7 | 271 | P. D. Staats | Traveling expenses | 23.84 |
| 7 | 272 | F. W. Clarke | ......do | 11.25 |
| 7 | 273 | N. R. D'Arcy | Subsistence supplies | 20.25 |
| 7 | 274 | ......do | Forage and transportation | 67.00 |
| 7 | 275 | ......do | Transportation of public property | 28.75 |
| 8 | 276 | R. C. Jones | Publications | 7.00 |
| 8 | 277 | J. W. Miller | Services | 3.00 |
| 8 | 278 | ......do | 1 horse | 40.00 |
| 8 | 279 | ......do | Services | 10.00 |
| 8 | 280 | ......do | Repairs | 8.50 |
| 8 | 281 | ......do | Subsistence supplies | 5.89 |
| 8 | 282 | ......do | Subsistence and field supplies | 80.28 |
| 8 | 283 | John Kelly | Subsistence supplies | 74.95 |
| 8 | 284 | ......do | Field material | 4.50 |
| 9 | 285 | Library Bureau | Stationery | 3.60 |

*Abstract of disbursements made by Jno. D. McChesney, etc.*—Continued.

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1887. | | | | |
| Dec. 9 | 286 | Walter L. Webb | Services, November, 1887 | $100.00 |
| 9 | 287 | Nat. K. Jones | Services, November 3 to 17, 1887 | 25.00 |
| 10 | 288 | Edward Orton | Services, July 1 to September 30, 1887. | 600.00 |
| 10 | 289 | Lawrence C. Johnson | Traveling expenses | 48.15 |
| 12 | 290 | Atchison, Topeka and Santa Fé Railroad. | Transportation of assistants | 179.75 |
| 12 | 291 | Photo. Engraving Company | Maps | 19.95 |
| 13 | 292 | Texas, Santa Fé and Northern Railroad. | Transportation of assistants | 38.40 |
| 13 | 293 | American Tool and Machine Company. | Laboratory supplies | 13.65 |
| 13 | 294 | Marcus E. Jones | Services | 15.00 |
| 13 | 295 | Charles S. Cudlip | Photographic supplies | 77.21 |
| 15 | 296 | W. M. Shuster & Sons | Office supplies | 21.49 |
| 15 | 297 | George Ryneal, jr | Office furniture | 15.19 |
| 15 | 298 | Charles H. Kraft | Laboratory supplies | 33.36 |
| 15 | 299 | St. Louis and San Francisco Railway. | Transportation of assistants | 57.35 |
| 17 | 300 | Hubbell, Merwin & Co | Laboratory material | 113.85 |
| 17 | 301 | Otis Brothers & Co | do | 8.78 |
| 17 | 302 | Western Union Telegraph Company. | Telegrams | 8.29 |
| 19 | 303 | C. W. Hayes | Services, November 1 to 30, 1887 | 50.00 |
| 19 | 304 | R. T. Hill | Traveling expenses | 40.90 |
| 19 | 305 | Chicago, Milwaukee and St. Paul Railroad. | Transportation of assistants | 89.50 |
| 19 | 306 | Robert Cameron | Repairs to public wagons | 16.00 |
| 20 | 307 | William Wesley & Son | Publications | 53.28 |
| 20 | 308 | Citizens' National Bank | Bill of exchange | .48 |
| 20 | 309 | Wabash Western Railway Company. | Transportation of assistants | 15.50 |
| 20 | 310 | W. H. Walmsley | Photographic supplies | 7.50 |
| 20 | 311 | C. W. Hall | Traveling expenses | 22.70 |
| 27 | 312 | L. B. Avery | do | 16.50 |
| 27 | 313 | W. J. McGee | do | 145.85 |
| 27 | 314 | Bailey Willis | Cash paid for freight | 1.75 |
| 29 | 315 | Edward Kübel | Cash paid for repairs | 12.28 |
| 29 | 317 | W. H. Lowdermilk & Co | Publications | 27.50 |
| 29 | 318 | John F. Stephenson | Freight charges | 15.90 |
| 29 | 319 | J. B. Woodworth | Services, November, 1887 | 50.00 |
| 30 | 320 | Mutual District Messenger Company. | Rental of night watch | 5.00 |
| 31 | 321 | Carl Barus | Traveling expenses | 28.05 |
| 31 | 322 | N. S. Shaler | Services, December, 1887 | 270.00 |
| 31 | 323 | Sam H. Scudder | do | 210.60 |
| 31 | 324 | J. Henry Blake | do | 151.60 |
| 31 | 325 | Walter L. Webb | do | 100.00 |
| 31 | 326 | William M. Fontaine | do | 168.50 |
| 31 | 326 | I. C. White | Services, October 1 to Dec. 13, 1887 | 402.15 |
| 31 | 327 | Lawrence C. Johnson | Services, December, 1887 | 117.90 |
| 31 | 328 | Leo Lesquereux | do | 75.00 |
| 31 | 329 | George H. Williams | Services, October 1 to December 20, 1887. | 80.00 |
| 31 | 330 | George H. Stone | Services, August 1 to November 30, 1887. | 100.00 |
| 31 | 331 | E. C. Anderson | Services, September 20 to October 4, 1887. | 30.00 |
| 31 | 332 | O. C. Marsh | Services, December, 1887 | 337.00 |
| 31 | 333 | A. Hermann | Services, October 1 to December 31, 1887. | 225.00 |
| 31 | 334 | T. A. Bostwick | do | 225.00 |
| 31 | 335 | R. W. Westbrook | do | 165.00 |
| 31 | 336 | G. Baur | Services, December, 1887 | 140.00 |
| 31 | 337 | E. H. Barbour | do | 134.80 |
| 31 | 338 | F. Berger | do | 70.00 |
| 31 | 339 | Hugh Gibb | do | 60.00 |
| 31 | 340 | L. P. Bush | do | 50.00 |
| 31 | 341 | Arthur Keith | do | 50.00 |
| 31 | 342 | August F. Foerste | Services, October 1 to December 31, 1887. | 90.00 |
| 31 | 343 | Roland D. Irving | Services, December, 1887 | 252.70 |
| 31 | 344 | Alfred Dodge | Laboratory supplies | 4.32 |
| 31 | 345 | James W. Queen & Co | Instruments, etc | 13.25 |
| 31 | 346 | Atlantic and Pacific Railroad | Transportation of assistants | 8.15 |
| 31 | 347 | Fremont, Elkhorn and Missouri Valley Railroad. | Transportation of freight | 99.77 |
| 31 | 348 | M. W. Beveridge | Office supplies | 2.46 |
| 31 | 349 | E. F. Brooks | Office furniture | 14.50 |
| 31 | 350 | H. Hoffa | Laboratory material | 2.90 |

*Abstract of disbursements made by Jno. D. McChesney, etc.*—Continued.

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1887. | | | | |
| Dec. 31 | 351 | Pay-roll of employés | Services, December, 1887 | $3,187.40 |
| 31 | 352 | ......do | ......do | 4,382.90 |
| 31 | 353 | ......do | ......do | 3,071.80 |
| 31 | 354 | ......do | ......do | 489.80 |
| 31 | 355 | ......do | ......do | 67.50 |
| 31 | 356 | ......do | ......do | 743.33 |
| 31 | 357 | George W. Shutt | ......do | 252.70 |
| 31 | 358 | W. N. Merriam | ......do | 117.90 |
| 31 | 359 | C. R. Van Hise | ......do | 80.00 |
| 31 | 360 | W. S. Bayley | ......do | 60.00 |
| 31 | 361 | C. W. Hall | Services between October 1 and December 17, 1887. | 27.00 |
| 31 | 362 | W. D. Heistand | Services, December, 1887 | 50.00 |
| 31 | 363 | Pay-roll of employés | ......do | 151.60 |
| 31 | 364 | Ira M. Buell | Services, November 24 to 26, 1887 | 12.00 |
| 31 | 365 | Baltimore and Ohio Railroad | Freight charges | 6.31 |
| 31 | 366 | N. S. Shaler | Traveling expenses | 110.83 |
| 31 | 367 | Warren Upham | ......do | 500.03 |
| 31 | 368 | Charles S. Cudlip | Photographic supplies | 346.98 |
| 31 | 369 | Washington Gas-Light Company. | Gas for December, 1887 | 115.39 |
| 31 | 370 | James G. Bowen | Care and forage of public animals | 59.94 |
| 31 | 371 | Bauch and Lamb Optical Company. | Office furniture | 4.00 |
| 31 | 372 | Washington City post-office | Rent of post-office boxes | 8.00 |
| 31 | 373 | Frank Leverett | Services, October 14 to December 31, 1887. | 300.00 |
| 31 | 374 | Lutz & Bro | Means of transportation | 80.50 |
| 31 | 375 | Chesapeake and Potomac Telephone Company. | Services, October, November, and December, 1887. | 155.50 |
| 31 | 376 | W. P. Rust | Services, December, 1887 | 60.75 |
| 31 | 377 | Hume, Cleary & Co | Office supplies | 9.30 |
| 31 | 378 | Great Falls Ice Company | Ice, October, November, and December, 1887. | 42.27 |
| 31 | 379 | B. F. McCaully & Co | Care and forage of public animals | 26.00 |
| 31 | 380 | Chicago and Alton Railroad | Transportation of assistants | 12.50 |
| 31 | 381 | Denver and Rio Grande Western Railroad. | ......do | 29.00 |
| | | | | 67,220.79 |

SALARIES OFFICE OF GEOLOGICAL SURVEY.

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1887. | | | | |
| Oct. 31 | 1 | Patrick Wheeler | Services, October, 1887 | 50.50 |
| 31 | 2 | Pay-roll of employés | ......do | 2,866.90 |
| 31 | 3 | A. B. Searle | ......do | 75.80 |
| Nov. 30 | 4 | Pay-roll of employés | Services, November, 1887 | 2,763.09 |
| Dec. 1 | 5 | Patrick Wheeler | ......do | 49.00 |
| 13 | 6 | M. W. Blumenberg | Services, December 1 to 8, 1887 | 10.43 |
| 31 | 7 | Pay-roll of employés | ......do | 2,901.82 |
| 31 | 8 | Jefferson Middleton | Services, December 17 to 31, 1887 | 41.58 |
| | | | | 8,759.12 |

*Abstract of disbursements made by C. D. Davis, special disbursing agent, U. S. Geological Survey, during the fourth quarter of* 1887.

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1887. | | | | |
| Dec. 2 | 1 | Clifford Arrick | Traveling expenses | $21.15 |
| 2 | 2 | ......do | Miscellaneous field expenses | 16.35 |
| 2 | 3 | R. H. Stuart | Traveling expenses | 14.22 |
| 3 | 4 | William H. Lovell | Miscellaneous field expenses | 57.20 |
| 6 | 5 | Sumner H. Bodfish | ......do | 95.65 |
| 8 | 6 | Willard D. Johnson | ......do | 127.73 |
| 9 | 7 | Raymond H. Hale | Traveling expenses | 17.11 |
| 9 | 8 | Henry Ulke, jr | ......do | 11.20 |
| 9 | 9 | ......do | Services, December, 1887 | 10.32 |
| 9 | 10 | G. L. Johnson | Traveling expenses | 14.17 |
| 10 | 11 | D. J. Howell | ......do | 65.16 |
| 12 | 12 | E. W. F. Natter | Miscellaneous field expenses | 155.75 |
| 12 | 13 | William H. Lovell | ......do | 19.44 |
| 12 | 14 | C. W. Fisherdick | Services, November, 1887 | 40.00 |
| 15 | 15 | Robert Robertson | Traveling expenses | 16.01 |
| 16 | 16 | Willard D. Johnson | Miscellaneous field expenses | 79.00 |

*Abstract of disbursements made by C. D. Davis, etc.*—Continued.

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1887. | | | | |
| Dec. 16 | 17 | Willard D. Johnson | Traveling expenses | $16.92 |
| 20 | 18 | E. W. F. Natter | Miscellaneous field expenses | 64.30 |
| 21 | 19 | William H. Lovell | ......do | 14.50 |
| 31 | 20 | Pay-roll of employés | Services, December, 1887 | 374.00 |
| 31 | 21 | .....do | ......do | 1,513.10 |
| 31 | 22 | Sumner H. Bodfish | Traveling expenses | 25.18 |
| | | | | 2,768.46 |

*Abstract of disbursements made by Mark B. Kerr, disbursing agent, U. S. Geological Survey, during the fourth quarter of* 1887.

| | | | | |
|---|---|---|---|---|
| 1887. | | | | |
| Oct. 1 | 1 | Leonard H. Swett | Traveling expenses | $33.00 |
| 3 | 2 | A. F. Dunnington | Field expenses | 24.85 |
| 3 | 3 | Redick H. McKee | ......do | 10.18 |
| 6 | 4 | H. M. Wilson | ......do | 125.17 |
| 6 | 5 | ......do | ......do | 43.00 |
| 6 | 6 | E. C. Ryan | ......do | 26.00 |
| 6 | 7 | ......do | Services, September, 1887 | 60.00 |
| 6 | 8 | James E. Shelley | Services, August, 1887 | 50.00 |
| 6 | 9 | Pay-roll (Diller) | Services, September, 1887 | 286.80 |
| 6 | 10 | C. H. Fitch | Field expenses | 59.97 |
| 6 | 11 | ......do | ......do | 37.75 |
| 6 | 12 | Frank Tweedy | ......do | 29.80 |
| 6 | 13 | Fred. J. Knight | ......do | 79.93 |
| 6 | 14 | ......do | ......do | 40.00 |
| 6 | 15 | A. T. Kyle, jr | Services, September, 1887 | 35.00 |
| 6 | 16 | ......do | Storage | 5.00 |
| 6 | 17 | ......do | Pasturage | 9.75 |
| 10 | 18 | James T. Jones | Traveling expenses | 17.00 |
| 10 | 19 | R. U. Goode | ......do | 72.60 |
| 10 | 20 | C. H. Fitch | Field expenses | 11.85 |
| 11 | 21 | Eugene Ricksecker | ......do | 186.95 |
| 12 | 22 | E. T. Perkins, jr | ......do | 38.50 |
| 12 | 23 | Peter Born | Services, October, 1887 | 17.41 |
| 12 | 24 | Miller & Co | Storage | 5.00 |
| 15 | 25 | L. G. Stevenson | Services, August and September, 1887. | 100.00 |
| 17 | 26 | A. H. Thompson | Services, September, 1887 | 220.20 |
| 17 | 27 | ......do | Traveling expenses | 99.46 |
| 31 | 28 | Pay-roll (Goode) | Services, October, 1887 | 337.40 |
| 31 | 29 | Pay-roll (Wallace) | ......do | 332.90 |
| 31 | 30 | Pay-roll (Fitch) | ......do | 332.70 |
| 31 | 31 | John B. Koch | Services, September, 1887 | 26.00 |
| 31 | 32 | Pay-roll (Douglas) | Services, October, 1887 | 261.88 |
| 31 | 33 | Pay-roll (Tweedy) | ......do | 257.05 |
| 31 | 34 | A. F. Dunnington | Traveling expenses | 120.20 |
| 31 | 35 | Redick H. McKee | ......do | 117.45 |
| 31 | 36 | H. M. Wilson | ......do | 123.95 |
| 31 | 37 | Owen W. Thomas, jr | ......do | 43.75 |
| 31 | 38 | F. M. Pierce | Subsistence, etc | 57.40 |
| 31 | 39 | D. W. Spence | Field expenses | 30.00 |
| 31 | 40 | .....do | Services | 8.06 |
| 31 | 41 | Pay-roll (office and field) | Services, October, 1887 | 609.90 |
| 31 | 42 | M. J. Holt | ......do | 38.71 |
| 31 | 43 | ......do | Traveling expenses | 95.50 |
| 31 | 44 | Paul Holman | ......do | 120.45 |
| 31 | 45 | Pay-roll (Davis) | Services, October, 1887 | 403.86 |
| 31 | 46 | Pay-roll (Knight) | ......do | 344.15 |
| 31 | 47 | H. S. Wallace | Field expenses | 97.50 |
| 31 | 48 | E. T. Perkins, jr | Traveling expenses | 123.95 |
| Nov. 5 | 49 | James E. Shelley | ......do | 26.00 |
| 4 | 50 | Mark B. Kerr | ......do | 117.50 |
| Oct. 31 | 51 | Pay-roll (Diller) | Services, October, 1887 | 301.60 |
| Nov. 15 | 52 | F. H. Tharp | Traveling expenses | 50.45 |
| 15 | 53 | James Vance | Storage | 30.00 |
| 15 | 54 | Arthur P. Davis | Field expenses | 55.66 |
| 16 | 55 | R. U. Goode | ......do | 48.30 |
| 16 | 56 | ......do | ......do | 41.30 |
| 9 | 57 | James E. Shelley | Traveling expenses | 19.50 |
| 14 | 58 | Eugene Ricksecker | Field expenses | 207.37 |
| 15 | 59 | H. S. Wallace | ......do | 42.98 |
| 16 | 60 | C. H. Fitch | ......do | 38.10 |
| 16 | 61 | ......do | ......do | 43.50 |
| 14 | 62 | Eugene Ricksecker | Traveling expenses | 139.75 |

*Abstract of disbursements made by Mark B. Kerr, etc.*—Continued.

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1887. | | | | |
| Nov. 14 | 63 | E. M. Douglas | Field expenses | $41.09 |
| 14 | 64 | ......do | Traveling expenses | 55.10 |
| 16 | 65 | R. H. Chapman | Field expenses | 9.30 |
| 16 | 66 | J. W. Miller | Field supplies | 15.55 |
| 16 | 67 | Frank Tweedy | Field expenses | 7.05 |
| 16 | 68 | C. H. Fitch | ......do | 57.40 |
| 16 | 69 | Frank Tweedy | Traveling expenses | 64.30 |
| 16 | 70 | Fred J. Knight | ......do | 131.25 |
| 16 | 71 | E. C. Landers | Forage | 200.00 |
| 16 | 72 | Pay-roll (Wilson) | Services, October, 1887 | 57.74 |
| 16 | 73 | E. M. Hasbrouck | Traveling expenses | 27.05 |
| 16 | 74 | John H. Hughes | Field material | 39.50 |
| 16 | 75 | C. H. Fitch | Traveling expenses | 63.45 |
| 16 | 76 | Charles F. Urquhart | ......do | 63.45 |
| 16 | 77 | Robert Muldrow | ......do | 63.20 |
| 16 | 78 | Hamilton S. Wallace | ......do | 63.45 |
| 16 | 79 | Houston Stevens | Services, October and November | 27.00 |
| 16 | 80 | D. H. Campbell | Services, November | 4.50 |
| 17 | 81 | R. U. Goode | Traveling expenses | 88.00 |
| 17 | 82 | ......do | Field expenses | 33.70 |
| 17 | 83 | ......do | ......do | 121.95 |
| 17 | 84 | H. S. Wallace | ......do | 25.05 |
| 17 | 85 | Frank E. Gore | ......do | 44.60 |
| 17 | 86 | Fred. J. Knight | ......do | 257.29 |
| 18 | 87 | E. M. Hasbrouck | ......do | 17.55 |
| 18 | 88 | ......do | ......do | 34.85 |
| 18 | 89 | ......do | ......do | 44.50 |
| 19 | 90 | Arthur P. Davis | Traveling expenses | 41.75 |
| 19 | 91 | W. R. Fitzgerald | Services, October, 1887 | 42.58 |
| 19 | 92 | T. H. Johnson | ......do | 30.65 |
| 19 | 93 | F. G. Pratt & Co | Subsistence, etc | 74.27 |
| 21 | 94 | J. J. Clark | Services, November, 1887 | 20.16 |
| 23 | 95 | A. H. Thompson | Services, October, 1887 | 227.40 |
| 25 | 96 | Frank H. Hughes | Services, September and October, 1887. | 55.00 |
| 25 | 97 | Lincoln Martin | Services, November, 1887 | 25.00 |
| 25 | 98 | ......do | Traveling expenses | 33.75 |
| 25 | 99 | James T. Jones | ......do | 16.50 |
| 25 | 100 | Frank H. Thorp | Services | 30.00 |
| 25 | 101 | Frank E. Gore | Services, November, 1887 | 25.00 |
| 25 | 102 | ......do | Traveling expenses | 63.40 |
| 25 | 103 | ......do | Field expenses | 44.50 |
| 26 | 104 | E. C. Ryan | Services, October, 1887 | 60.00 |
| 26 | 105 | ......do | Traveling expenses | 85.00 |
| 26 | 106 | ......do | Board and lodging | 8.60 |
| 28 | 107 | J. S. Diller | Traveling expenses | 86.00 |
| 28 | 108 | ......do | ......do | 615.74 |
| 30 | 109 | Pay-roll (office and field) | Services, November, 1887 | 2,027.40 |
| 30 | 110 | R. H. Chapman | Services, October and November | 165.80 |
| 30 | 111 | J. R. Curlee | Shoeing | 8.00 |
| 30 | 112 | L. B. Putney | Forage | 17.95 |
| 30 | 113 | Arthur P. Davis | Field expenses | 113.35 |
| 30 | 114 | ......do | ......do | 46.54 |
| 30 | 115 | Charles W. Howell | Services, November, 1887 | 60.00 |
| 30 | 116 | A. T. Kyle, jr | Pasturage | 40.57 |
| 30 | 117 | C. Beach | Field stationery | 5.03 |
| Dec. 1 | 118 | C. P. Rock | Traveling expenses | 80.90 |
| 1 | 119 | ......do | ......do | 46.77 |
| 1 | 120 | ......do | ......do | 36.29 |
| 2 | 121 | Warren H. Moons | Forage | 31.88 |
| 5 | 122 | R. H. Chapman | Traveling expenses | 29.40 |
| 5 | 123 | James T. Jones | Services, October, 1887 | 50.00 |
| 7 | 124 | E. M. Hasbrouck | Services, November, 1887 | 50.00 |
| 8 | 125 | Zellhoefer & Noedel | Subsistence | 53.75 |
| 8 | 126 | Mark B. Kerr | Field expenses | 90.83 |
| 14 | 127 | Joseph W. Davis | Field material | 5.00 |
| 14 | 128 | John H. Hughes | ......do | 55.00 |
| 14 | 129 | A. Leitz & Co. | Repairs to instruments | 9.75 |
| 14 | 130 | Amos Scott | Services, October, 1887 | 32.90 |
| 15 | 131 | L. B. Putney | Forage | 61.50 |
| 23 | 132 | A. H. Thompson | Traveling expenses | 165.93 |
| 27 | 133 | J. D. Black | Services, September, 1887 | 30.00 |
| 27 | 134 | John H. Hughes | Field material | 6.75 |
| 27 | 135 | L. B. Putney | Forage | 9.58 |
| 31 | 136 | Pay-roll (office and field) | Services, December, 1887 | 2,360.30 |
| 31 | 137 | J. T. Miller | Herding and pasture | 82.50 |
| 31 | 138 | Charles W. Howell | Services, December, 1887 | 60.00 |
| | | | | 15,846.78 |

*Abstract of disbursements made by P. H. Christie, special disbursing agent, U. S. Geological Survey, during the fourth quarter of* 1887.

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1887 | | | | |
| Oct. 10 | 1 | R. Lee Longstreet | Miscellaneous field expenses | $26.65 |
| 11 | 2 | Charles M. Yeates | ......do | 76.42 |
| 12 | 3 | D. C. Harrison | ......do | 41.50 |
| 13 | 4 | E. C. Barnard | ......do | 76.08 |
| 13 | 5 | Morris Bien | ......do | 133.19 |
| 15 | 6 | J. W. Hays | ......do | 78.48 |
| 15 | 7 | W. T. Griswold | ......do | 21.92 |
| 15 | 8 | ......do | ......do | 27.57 |
| 15 | 9 | ......do | ......do | 28.15 |
| 15 | 10 | Louis Nell | ......do | 20.00 |
| 17 | 11 | M. Hackett | ......do | 166.32 |
| 17 | 12 | L. C. Fletcher | ......do | 94.58 |
| 17 | 13 | W. T. Griswold | Traveling expenses | 59.25 |
| 18 | 14 | Louis Nell | Miscellaneous field expenses | 166.32 |
| 24 | 15 | D. C. Harrison | ......do | 13.50 |
| 24 | 16 | E. C. Barnard | Traveling expenses | 8.86 |
| 24 | 17 | W. T. Griswold | Miscellaneous field expenses | 53.78 |
| 25 | 18 | R. O. Gordon | ......do | 36.29 |
| 26 | 19 | L. C. Fletcher | ......do | 79.20 |
| 27 | 20 | Morris Bien | ......do | 129.74 |
| 28 | 21 | Z. N. Lockhart | Stock | 160.00 |
| 30 | 22 | ......do | Forage of stock, etc | 69.59 |
| 31 | 23 | Pay-roll | Services, October, 1887 | 355.30 |
| 31 | 24 | P. H. Christie | ......do | 151.60 |
| 31 | 25 | J. D. Hanger | ......do | 40.00 |
| 31 | 26 | Pay-roll | ......do | 401.40 |
| 31 | 27 | D. C. Harrison | ......do | 101.10 |
| 31 | 28 | R. Lee Longstreet | ......do | 84.20 |
| 31 | 29 | J. W. Hays | ......do | 101.10 |
| 31 | 30 | W. T. Griswold | ......do | 151.60 |
| 31 | 31 | V. T. Carmichael | ......do | 25.00 |
| 31 | 32 | W. G. Cleland | ......do | 25.00 |
| 31 | 33 | Pay-roll | ......do | 595.63 |
| 31 | 34 | Tinsley Racener | ......do | 20.00 |
| 31 | 35 | E. S. Bodenhamer | ......do | 12.00 |
| 31 | 36 | R. C. McKinney | ......do | 101.10 |
| 31 | 37 | John W. Carter | ......do | 12.09 |
| 31 | 38 | F. P. Fitzwilliam | ......do | 25.00 |
| 31 | 39 | Pay-roll (Barnard, October) | ......do | 351.90 |
| 31 | 40 | Pay-roll (Nell, October) | ......do | 541.40 |
| 31 | 41 | Pay-roll (Bien, October) | ......do | 353.00 |
| 31 | 42 | W. F. Fling | Forage of stock | 4.00 |
| 31 | 43 | R. C. McKinney | Miscellaneous field expenses | 21.90 |
| Nov. 4 | 44 | Charles M. Yeates | ......do | 435.04 |
| 10 | 45 | R. Lee Longstreet | ......do | 49.29 |
| 10 | 46 | Louis Nell | ......do | 77.60 |
| 11 | 47 | R. C. McKinney | ......do | 36.63 |
| 12 | 48 | L. C. Fletcher | ......do | 70.22 |
| 12 | 49 | ......do | Traveling expenses | 29.25 |
| 14 | 50 | Lewis J. Battle | Services, November 1 to 14, 1887, inclusive. | 23.33 |
| 16 | 51 | M. B. Harrolson | Services, November 1 to 7, 1887, inclusive. | 9.33 |
| 16 | 52 | ......do | Miscellaneous field expenses | 14.65 |
| 30 | 53 | F. P. Fitzwilliam | Services, November 1 to 12, 1887, inclusive. | 10.00 |
| 30 | 54 | Pay-roll (office) | Services, November, 1887 | 1,533.20 |
| 30 | 55 | ......do | ......do | 456.53 |
| 30 | 56 | ......do | ......do | 399.80 |
| 30 | 57 | ......do | ......do | 382.19 |
| 30 | 58 | James Graham | Services, November 1 to 8, 1887, inclusive. | 13.33 |
| 30 | 59 | R. Lee Longstreet | Miscellaneous field expenses | 19.24 |
| 30 | 60 | M. Hackett | ......do | 163.34 |
| 30 | 61 | R. McC. Michler | Traveling expenses | 38.15 |
| 30 | 62 | A. E. Murlin | ......do | 44.65 |
| 30 | 63 | M. Hackett | ......do | 32.65 |
| 30 | 64 | Gilbert Thompson | ......do | 17.65 |
| 30 | 65 | W. R. Atkinson | ......do | 33.20 |
| 30 | 66 | C. W. Goodlow | ......do | 39.60 |
| 30 | 67 | Shack Smith | ......do | 18.25 |
| 30 | 68 | Lewis J. Battle | ......do | 19.30 |
| 30 | 69 | R. O. Gordon | ......do | 19.10 |
| 30 | 70 | W. L. Miller | ......do | 21.50 |
| 30 | 71 | Charles E. Cooke | ......do | 10.10 |
| 30 | 72 | D. C. Harrison | ......do | 17.25 |
| 30 | 73 | R. Lee Longstreet | ......do | 17.70 |
| 30 | 74 | Hersey Monroe | ......do | 12.60 |

*Abstract of disbursements made by P. H. Christie, etc.*—Continued.

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1887. | | | | |
| Nov. 30 | 75 | R. M. Towson | Traveling expenses | $26.75 |
| 30 | 76 | T. Booker | ......do | 3.70 |
| 30 | 77 | Morris Bien | ......do | 8.25 |
| 30 | 78 | ......do | ......do | 22.95 |
| 30 | 79 | Louis Nell | ......do | 74.00 |
| 30 | 80 | Frederic P. Gulliver | ......do | 31.40 |
| 30 | 81 | E. C. Barnard | ......do | 25.05 |
| 30 | 82 | P. H. Christie | ......do | 103.45 |
| 30 | 83 | Morris Bien | Miscellaneous field expenses | 117.05 |
| 30 | 84 | John W. Emmert | Traveling expenses | 6.60 |
| 30 | 85 | W. L. Miller | Miscellaneous field expenses | 31.40 |
| 30 | 86 | R. O. Gordon | ......do | 88.41 |
| 30 | 87 | D. C. Harrison | ......do | 24.00 |
| 30 | 88 | ......do | ......do | 17.92 |
| 30 | 89 | J. W. Hays | ......do | 69.75 |
| 30 | 90 | Morris Bien | ......do | 159.26 |
| 30 | 91 | W. T. Griswold | ......do | 211.23 |
| 30 | 92 | ......do | Traveling expenses | 6.93 |
| 30 | 93 | E. C. Barnard | Miscellaneous field expenses | 200.66 |
| 30 | 94 | W. F. Fling | Forage of stock | 12.00 |
| 30 | 95 | N. B. Dunn | ......do | 168.75 |
| 30 | 96 | L. Morgan | ......do | 16.50 |
| Dec. 13 | 97 | R. C. McKinney | Traveling expenses | 10.65 |
| 13 | 98 | ......do | ......do | 15.20 |
| 14 | 99 | Louis Nell | Miscellaneous field expenses | 232.02 |
| 14 | 100 | C. B. Buxton | Traveling expenses | 25.50 |
| 17 | 101 | R. Lee Longstreet | Miscellaneous field expenses | 45.12 |
| 17 | 102 | L. Morgan | Traveling expenses | 12.80 |
| 17 | 103 | E. C. Barnard | Miscellaneous field expenses | 2.65 |
| 19 | 104 | L. D. Brent | ......do | 21.85 |
| 19 | 105 | ......do | Traveling expenses | 26.30 |
| 19 | 106 | W. G. Cleland | Miscellaneous field expenses | 10.00 |
| 20 | 107 | Louis Nell | ......do | 170.39 |
| 20 | 108 | Charles M. Yeates | Traveling expenses | 28.75 |
| 21 | 109 | Morris Bien | Miscellaneous field expenses | 68.96 |
| 21 | 110 | Charles M. Yeates | ......do | 144.45 |
| 23 | 111 | John W. Emmert | ......do | 40.14 |
| 23 | 112 | P. H. Christie | ......do | 91.36 |
| 31 | 113 | Pay-roll | Services, December, 1887 | 2,638.63 |
| 31 | 114 | A. E. Wilson | Traveling expenses | 23.60 |
| 31 | 115 | J. W. Hays | ......do | 18.60 |
| 31 | 116 | ......do | Miscellaneous field expenses | 74.08 |
| 31 | 117 | Carroll Webster | Traveling expenses | 1.60 |
| 31 | 118 | Elias Foglesong | Forage of stock | 6.30 |
| 31 | 119 | W. F. Fling | ......do | 18.84 |
| 31 | 120 | Z. N. Lockhart | ......do | 8.33 |
| 31 | 121 | James G. Reaves | Forage of stock, etc | 56.02 |
| 31 | 122 | W. F. Latham | ......do | 70.38 |
| 31 | 123 | E. M. Harnsberger | ......do | 100.00 |
| 31 | 124 | L. Morgan | ......do | 65.00 |
| 31 | 125 | M. H. Horton | Storage of property | 6.00 |
| 31 | 126 | Henkel & Corpening | ......do | 3.00 |
| 31 | 127 | A. E. Wilson | Miscellaneous field expenses | 3.50 |
| 31 | 128 | N. B. Dunn | Forage of stock | 176.94 |
| 31 | 129 | A. Slack, M. D | Veterinary services | 8.20 |
| 31 | 130 | N. B. Dunn | Miscellaneous field expenses | 25.00 |
| | | | | 14,782.55 |

*Abstract of disbursements made by Arnold Hague, special disbursing agent, U. S. Geological Survey, during the fourth quarter of* 1887.

| | | | | |
|---|---|---|---|---|
| 1887. | | | | |
| Sept. 30 | 1 | Pay-roll of employés | Salaries, September, 1887 | $1,228.20 |
| Oct. 4 | 2 | Arnold Hague | Traveling expenses | 53.85 |
| 4 | 3 | Yellowstone Park Association | Field subsistence and material | 201.85 |
| 4 | 4 | ......do | Subsistence | 28.75 |
| 5 | 5 | James A. Clark | Field supplies | 65.70 |
| Nov. 5 | 6 | Anton Karl | Traveling expenses | 32.50 |
| 12 | 7 | E. J. Owenhouse | Storage | 15.00 |
| Oct. 31 | 8 | Pay-roll of employés | Salaries, field force, October, 1887 | 411.72 |
| Nov. 14 | 9 | W. H. Weed | Traveling expenses | 60.35 |
| 14 | 10 | Joseph P. Iddings | ......do | 30.47 |
| 15 | 11 | E. H. Shuster | ......do | 30.87 |
| Oct. 31 | 12 | Pay-roll of employés | Salaries, October, 1887 | 698.40 |

*Abstract of disbursements made by Arnold Hague, etc.*—Continued.

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1887. | | | | |
| Nov. 19 | 13 | E. A. Rouse | Forage public animals | $44.80 |
| 19 | 14 | Arnold Hague | Traveling expenses | 83.60 |
| 19 | 15 | .....do | Miscellaneous expenses | 88.79 |
| 21 | 16 | J. C. McCartney | Field supplies | 40.27 |
| 30 | 17 | Pay-roll of employés | Salaries, November, 1887 | 678.20 |
| Dec. 1 | 18 | A. C. Gill | Traveling expenses | 22.90 |
| 5 | 19 | A. Lamme & Co | Field subsistence | 180.70 |
| 5 | 20 | H. J. Hoppe | ......do | 5.90 |
| 21 | 21 | Henry J. Green | Instruments and repairs | 55.15 |
| 31 | 32 | Pay-roll of employés | Salaries, November, 1887 | 724.20 |
| | | | | 4,782.17 |

*Abstract of disbursements made by A. O. D. Taylor, jr., special disbursing agent, U. S. Geological Survey, during the fourth quarter of* 1887.

| | | | | |
|---|---|---|---|---|
| 1887. | | | | |
| Oct. 4 | 1 | T. Nelson Dale | Traveling expenses | $24.88 |
| 11 | 2 | L. E. Paddock | ......do | 15.30 |
| 11 | 3 | .....do | Incidental expenses | 5.88 |
| 11 | 4 | .... do | Pay for services in July and August, 1887. | 40.00 |
| 13 | 5 | William H. Hobbs | Traveling expenses | 24.84 |
| 13 | 6 | Henry W. Cozzens, jr | One fuse cartridge | 2.25 |
| 14 | 7 | H. L. Smyth | Incidental field expenses | 85.25 |
| 18 | 8 | Buff & Berger | Repairing alidade, etc | 17.60 |
| 18 | 9 | Darling, Brown & Sharpe | One steel rule | 6.50 |
| 25 | 10 | W. & L. E. Gurley | Instruments, etc | 17.07 |
| 25 | 11 | Henry J. Green | One aneroid barometer, etc | 24.25 |
| 25 | 12 | | (Disallowed.) | |
| 25 | 13 | J. Eliot Wolff | Miscellaneous field expenses | 5.03 |
| 26 | 14 | Ben. K. Emerson | Traveling expenses | 142.22 |
| 26 | 15 | T. Nelson Dale | ......do | 48.91 |
| 26 | 16 | ......do | Miscellaneous field expenses | 14.15 |
| 26 | 17 | J. H. Flagg | Team hire | 175.45 |
| 26 | 18 | H. L. Smyth | Field expenses and subsistence | 201.71 |
| 26 | 19 | W. M. Davis | Traveling expenses | 18.90 |
| 26 | 20 | ......do | Services in July, August, and September, 1887. | 17.50 |
| 26 | 21 | C. L. Whittle | Traveling expenses | 24.00 |
| 31 | 22 | Raphael Pumpelly | Pay for October, 1887 | 337.00 |
| 31 | 23 | T. Nelson Dale | ......do | 150.00 |
| 31 | 24 | A. O. D. Taylor, jr | ......do | 101.10 |
| 31 | 25 | H. L. Smyth | ......do | 84.20 |
| 31 | 26 | W. R. Smyth | ......do | 40.00 |
| 31 | 27 | James McCormick | ......do | 9.03 |
| 31 | 28 | J. F. Allison | ......do | 12.90 |
| 31 | 29 | A. Prescott Baker | Rent for October | 50.00 |
| 31 | 30 | H. L. Smyth | Traveling expenses | 12.27 |
| Nov. 3 | 31 | ......do | Miscellaneous field expenses | 87.72 |
| 4 | 32 | Newport Transfer Express Company. | Freight and cartage | 12.03 |
| 7 | 33 | Algernon B. Corbin | Stationery, etc | 9.33 |
| 10 | 34 | Western Union Telegraph Company. | Telegrams | 6.15 |
| 10 | 35 | Michael Cottrell | One chest of drawers | 28.00 |
| 10 | 36 | Adams Express Company | Express charges | 3.65 |
| 11 | 37 | New York and Boston Dispatch Express Company. | ......do | 5.75 |
| 26 | 38 | C. L. Whittle | Field expenses | 12.78 |
| 29 | 39 | Frost & Adams | Drawing materials | 23.96 |
| 30 | 40 | Raphael Pumpelly | Pay for November, 1887 | 326.00 |
| 30 | 41 | H. L. Smyth | ......do | 81.60 |
| 30 | 42 | T. Nelson Dale | ......do | 150.00 |
| 30 | 43 | A. O. D. Taylor, jr | ......do | 97.80 |
| 30 | 44 | A. Prescott Baker | Rent for November, 1887 | 50.00 |
| Dec. 2 | 45 | W. R. Smyth | Traveling expenses | 8.47 |
| 6 | 46 | ......do | Pay for November, 1887 | 9.33 |
| 6 | 47 | Raphael Pumpelly | Traveling expenses | 116.00 |
| 6 | 48 | H. L. Smyth | ......do | 11.04 |
| 6 | 49 | ......do | Miscellaneous expenses | 45.40 |
| 14 | 50 | Ben. K. Emerson | Traveling expenses | 63.61 |
| 14 | 51 | C. L. Whittle | ......do | 82.18 |
| 14 | 52 | J. Eliot Wolff | Pay for November, 1887 | 55.43 |
| 14 | 53 | Raphael Pumpelly | Office expenses | 39.90 |
| 15 | 54 | Kneffel & Esser | Drawing material | 12.76 |

*Abstract of disbursements made by A. O. D. Taylor, jr., etc.*—Continued.

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1887. | | | | |
| Dec. 17 | 55 | C. L. Whittle | Pay for October and November, 1887. | $37.73 |
| 31 | 56 | Raphael Pumpelly | Pay for December, 1887 | 337.00 |
| 31 | 57 | H. L. Smyth | do | 84.20 |
| 31 | 58 | T. Nelson Dale | do | 150.00 |
| 31 | 59 | A. O. D. Taylor, jr | do | 101.10 |
| 31 | 60 | Henry Bull, jr | Telephone rent | 11.50 |
| 31 | 61 | A. Prescott Baker | Rent for December, 1887 | 50.00 |
| 31 | 62 | J. Eliot Wolff | Pay for December, 1887 | 48.91 |
| 31 | 63 | Richard Bliss | Bibliographical work | 71.40 |
| | | | | 3,938.92 |

*Abstract of disbursements made by Fielding Burnes, disbursing agent, U. S. Geological Survey, during the fourth quarter of* 1887.

| | | | | |
|---|---|---|---|---|
| 1887. | | | | |
| Oct. 6 | 1 | William H. Lovell | Miscellaneous field expenses | $28.10 |
| 6 | 2 | E. B. Clark | do | 51.00 |
| 6 | 3 | Willard D. Johnson | do | 105.15 |
| 7 | 4 | C. C. Bassett | do | 59.17 |
| 7 | 5 | Robert D. Cummin | do | 55.48 |
| 7 | 6 | Laurence Thompson | do | 56.78 |
| 10 | 7 | E. C. Robinson | Transportation | 200.00 |
| 10 | 8 | E. W. F. Natter | Miscellaneous field expenses | 281.53 |
| 11 | 9 | S. H. Bodfish | do | 202.06 |
| 12 | 10 | do | Traveling expenses | 24.65 |
| 15 | 11 | E. W. F. Natter | do | 45.79 |
| 15 | 12 | do | do | 30.59 |
| 18 | 13 | J. H. Jennings | do | 26.36 |
| 19 | 14 | W. H. Lovell | Miscellaneous field expenses | 33.84 |
| 19 | 15 | E. B. Clark | do | 55.00 |
| 19 | 16 | C. C. Bassett | do | 62.25 |
| 21 | 17 | Eugene Pierce | Traveling expenses | 2.15 |
| 22 | 18 | Willard D. Johnson | Miscellaneous field expenses | 105.87 |
| 24 | 19 | Charles C. Bassett | Traveling expenses | 7.19 |
| 25 | 20 | E. W. F. Natter | do | 24.85 |
| 25 | 21 | do | Miscellaneous field expenses | 238.40 |
| 27 | 22 | Robert D. Cummin | do | 59.67 |
| 27 | 23 | Sumner H. Bodfish | do | 89.62 |
| 31 | 24 | Laurence Thompson | Services, October, 1887 | 84.20 |
| 31 | 25 | William H. Lovell | do | 84.20 |
| 31 | 26 | C. J. Akin | do | 60.00 |
| 31 | 27 | Charles C. Bassett | do | 84.20 |
| 31 | 28 | Robert D. Cummin | do | 101.10 |
| 31 | 29 | E. B. Clark | do | 75.80 |
| 31 | 30 | James Longtreet, jr | do | 50.50 |
| 31 | 31 | Lawson Sandford | do | 50.00 |
| 31 | 32 | G. L. Johnson | do | 50.00 |
| 31 | 33 | W. E. Horton | do | 50.00 |
| 31 | 34 | Pay-roll of employés | do | 1,021.82 |
| 31 | 35 | Sumner H. Bodfish | do | 168.50 |
| 31 | 36 | E. G. Kennedy | do | 50.00 |
| 31 | 37 | J. H. Jennings | do | 84.20 |
| 31 | 38 | Fielding Burnes | Services, July 1 to October 31, 1887. | 601.60 |
| Nov. 1 | 39 | Nat K. Jones | Traveling expeuses | 15.75 |
| 2 | 40 | Marcus Baker | do | 66.51 |
| 2 | 41 | Robert D. Cummin | Miscellaneous field expenses | 66.71 |
| 2 | 42 | J. H. Jennings | do | 2.00 |
| 3 | 43 | Willard D. Johnson | do | 109.76 |
| 4 | 44 | William H. Lovell | do | 87.31 |
| 4 | 45 | C. C. Bassett | do | 59.46 |
| 4 | 46 | Nat. K Jones | Services | 1.66 |
| 4 | 47 | E. B. Clark | Miscellaneous field expenses | 62.00 |
| 7 | 48 | Laurence Thompson | do | 130.86 |
| 8 | 49 | E. W. F. Natter | do | 272.75 |
| 8 | 50 | do | Traveling expenses | 27.15 |
| 10 | 51 | E. C. Robinson | Transportation | 170.97 |
| 17 | 52 | Willard D. Johnson | Miscellaneous field expenses | 109.90 |
| 17 | 53 | William H. Lovell | do | 59.50 |
| 18 | 54 | Robert D. Cummin | do | 39.45 |
| 18 | 55 | do | Traveling expenses | 44.00 |
| 19 | 56 | E. B. Clark | do | 17.60 |
| 19 | 57 | W. E. Horton | do | 15.25 |
| 21 | 58 | Sumner H. Bodfish | do | 62.12 |
| 21 | 59 | do | Miscellaneous field expenses | 118.50 |

*Abstract of disbursements made by Fielding Burnes, etc.*—Continued.

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1887. | | | | |
| Nov. 21 | 60 | Sumner H. Bodfish | Miscellaneous field expenses | $79.72 |
| 22 | 61 | E. B. Clark | ......do | 51.50 |
| 22 | 62 | C. C. Bassett | ......do | 25.68 |
| 22 | 63 | ......do | Traveling expenses | 26.01 |
| 22 | 64 | James Longstreet, jr | ......do | 15.77 |
| 23 | 65 | E. W. F. Natter | Miscellaneous field expenses | 303.44 |
| 23 | 66 | Laurence Thompson | Traveling expenses | 18.35 |
| 23 | 67 | C. J. Akin | ......do | 15.74 |
| 23 | 68 | E. G. Kennedy | ......do | 1.95 |
| 26 | 69 | E. W. F. Natter | ......do | 36.15 |
| 28 | 70 | Laurence Thompson | Miscellaneous field expenses | 112.90 |
| 28 | 71 | E. C. Robinson | Transportation | 38.33 |
| 28 | 72 | J. H. Jennings | Traveling expenses | 16.60 |
| 30 | 73 | Sumner H. Bodfish | Services, November, 1887 | 163.00 |
| 30 | 74 | Pay-roll of employés | ......do | 765.40 |
| 30 | 75 | ......do | ......do | 1,099.20 |
| Dec. 2 | 76 | Lawson Sandford | Traveling expenses | 21.18 |
| 10 | 77 | Sumner H. Bodfish | ......do | 44.43 |
| 10 | 78 | E. W. F. Natter | ......do | 19.90 |
| 21 | 79 | ......do | ......do | 14.05 |
| 31 | 80 | Fielding Burnes | Services, December, 1887 | 151.60 |
| | | | | 9,021.73 |

*Abstract of disbursements made by R. R. Hawkins, special disbursing agent, U. S. Geological Survey, during the fourth quarter of* 1887.

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1887. | | | | |
| Oct. 25 | 1 | A. Carlisle & Co | Field, laboratory, and office supplies. | $52.75 |
| 27 | 2 | F. C. Boyce | Services, October 1 to 10, 1887, inclusive. | 20.00 |
| 28 | 3 | H. W. Turner | Field expenditures | 30.81 |
| 28 | 4 | ......do | ......do | 48.60 |
| 28 | 5 | Albert Lasey | Map | 10.00 |
| 31 | 6 | Charles McLaren | Services, October, 1887 | 65.00 |
| 31 | 7 | Albion S. Howe | ......do | 60.00 |
| 31 | 8 | Pay-roll | ......do | 591.30 |
| 31 | 9 | Frank Rader | ......do | 30.00 |
| Nov. 1 | 10 | G. W. Grannis | Rent of rooms | 105.32 |
| 2 | 11 | E. M. Sleator | Map | 3.50 |
| 4 | 12 | W. Lindgren | Field expenditures | 50.60 |
| 5 | 13 | ......do | Traveling expenses | 5.25 |
| 9 | 14 | A. J. Bien | Repairs | 10.20 |
| 14 | 15 | H. W. Turner | Field expenditures | 35.29 |
| 14 | 16 | ......do | Traveling expenses | 19.45 |
| 14 | 17 | Frank Rader | Services, November 1 to 15, 1887, inclusive. | 15.00 |
| 20 | 18 | Pay-roll | ......do | 572.40 |
| 30 | 19 | Albion S. Howe | ......do | 60.00 |
| Dec. 2 | 20 | Martin Peterson | Laboratory fixtures, etc | 16.11 |
| 6 | 21 | H. L. Howse | Laboratory and office supplies | 7.65 |
| 6 | 22 | George Spaulding & Co | Labels | 5.00 |
| 6 | 23 | L. A. Bertling | Magnifying glass, etc | 2.50 |
| 6 | 24 | J. J. Vasconcellos | Field and office supplies | 9.05 |
| 6 | 25 | L. Jones | Services | 4.05 |
| 31 | 26 | | (Disallowed.) | |
| 31 | 27 | Pay-roll | Services, December, 1887 | 591.30 |
| 31 | 28 | Albion S. Howe | ......do | 60.00 |
| 31 | 29 | G. W. Grannis | Rent of rooms | 105.32 |
| 31 | 30 | R. R. Hawkins | Sundry cash expenditures | 23.83 |
| | | | | 2,610.28 |

*Abstract of disbursements made by Alfred M. Rogers, disbursing agent, U. S. Geological Survey, during the fourth quarter of* 1887.

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1887. | | | | |
| Oct. 10 | 1 | P. H. Van Diest | Services, October 10, 1887 | $4.50 |
| 15 | 2 | S. F. Emmons | Traveling expenses | 36.35 |
| 26 | 3 | Robert Mason | Services, October 21 to 25, 1887, inclusive. | 10.25 |
| 31 | 4 | Pay-roll | October, 1887 | 763.11 |
| Nov. 28 | 5 | U. Robinson | Services | 1.00 |
| 30 | 6 | Pay-roll | November, 1887 | 696.60 |

*Abstract of disbursements made by Alfred M. Rogers, etc.*—Continued.

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1887. | | | | |
| Dec. 10 | 7 | M. McIntyre | Services | $6.25 |
| 10 | 8 | B. F. McCracken | Field subsistence | 11.00 |
| 12 | 9 | Block & Carlisle | ......do | 89.28 |
| 12 | 10 | ......do | ......do | 16.77 |
| 14 | 11 | John McCosker | Field supplies and expenses | 59.90 |
| 14 | 12 | Miller & Miller | ......do | 40.27 |
| 16 | 13 | Wallace & Fraser | Field subsistence | 31.53 |
| 16 | 14 | W. B. Smith | Traveling expenses | 27.75 |
| 19 | 15 | Dumbaugh & Joy | Field subsistence | 23.85 |
| 19 | 16 | ......do | ......do | 41.06 |
| 19 | 17 | ......do | ......do | 52.29 |
| 10 | 18 | C. Weinberger | Traveling expenses | 50.15 |
| 10 | 19 | A. Glover | ......do | 14.70 |
| 10 | 20 | Charles Julian | Field supplies and expenses | 11.30 |
| 31 | 21 | A. J. Allison | Field subsistence | 6.61 |
| 31 | 22 | S. F. Emmons | Traveling expenses | 65.90 |
| 31 | 23 | ......do | Pay, October 1 to December 31, 1887 | 1,000.00 |
| 31 | 24 | E. H. Hill | Field supplies and expenses | 52.00 |
| 31 | 25 | Scott & Murch | Transportation of property | 76.75 |
| 31 | 26 | Sam P. Barber | Rent | 159.40 |
| 31 | 27 | Pay-roll | December, 1887 | 693.70 |
| 31 | 28 | C. Whitman Cross | Traveling expenses | 187.60 |
| 31 | 29 | The Denver Water Company | Laboratory expenses | 37.50 |
| 31 | 30 | Chain, Hardy & Co | Stationery and photo. material | 73.28 |
| 31 | 31 | V. F. Axtell | Field expenses | 61.42 |
| 31 | 32 | Daniels & Fisher | Transportation of property | .80 |
| 31 | 33 | H. E. Sylvester & Co | Office supplies | 15.00 |
| 31 | 34 | R. M. Davis | Photo. material | 2.67 |
| 31 | 35 | W. H. Lawrence & Co | Stationery | 2.15 |
| 31 | 36 | W. G. Trimble | Laboratory material | 11.50 |
| 31 | 37 | H. Z. Salomon | Office supplies | 1.00 |
| 31 | 38 | C. A. Roberts & Co | Office material and supplies | 1.00 |
| 31 | 39 | Kerstens, Peters & Co | Office supplies and transportation of property. | 13.70 |
| 31 | 40 | J. O. Bosworth | Laboratory material and transportation of property. | 30.48 |
| 31 | 41 | Denver post-office | Correspondence | 2.50 |
| 31 | 42 | Wells, Fargo & Company's Express. | Transportation of property | 9.00 |
| 31 | 43 | William L. Patten & Co | Field material | 11.68 |
| 31 | 44 | Dan Phillips | Services, October, November, and December, 1887. | 9.90 |
| 31 | 45 | William Dingle | Office supplies | 6.65 |
| 31 | 46 | Peter McCourt | Rent | 150.00 |
| 31 | 47 | Denver and Rio Grande Railroad Company. | Transportation of property | 17.05 |
| | | | | 4,687.15 |

*Abstract of disbursements made by Jno. H. Renshawe, disbursing agent, U. S. Geological Survey, during the fourth quarter of* 1887.

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1887. | | | | |
| Oct. 3 | 1 | H. L. Baldwin, jr | Field expenses | $117.51 |
| 6 | 2 | S. S. Gannett | ......do | 190.10 |
| 7 | 3 | H. B. Blair | ......do | 144.47 |
| 7 | 4 | ......do | ......do | 139.95 |
| 7 | 5 | Pay-roll | Services, September | 298.40 |
| 7 | 6 | ......do | ......do | 347.60 |
| 7 | 7 | ......do | ......do | 293.00 |
| 15 | 8 | J. E. Hill | ......do | 60.00 |
| 15 | 9 | John H. Renshawe | Traveling expenses | 104.52 |
| 18 | 10 | S. S. Gannett | Field expenses | 298.50 |
| 19 | 11 | G. J. Corscot | 1 atlas (Dane County, Wis.) | 15.00 |
| 20 | 12 | A. L. Skeels | Hotel bill, etc | 22.00 |
| 23 | 13 | William J. Peters | Field expenses | 21.44 |
| 23 | 14 | H. L. Baldwin, jr | ......do | 77.32 |
| 27 | 15 | A. L. Skeels | Hotel bill | 20.75 |
| 31 | 16 | William J. Peters | Services | 198.90 |
| 31 | 17 | C. T. Reid | ......do | 100.00 |
| 31 | 18 | John H. Renshawe | ......do | 210.60 |
| Nov. 2 | 19 | C. W. Hawkins | Traveling expenses | 37.05 |
| 2 | 20 | Ernest M. Warren | Forage, etc | 17.50 |
| 2 | 21 | Pay-roll | Services, October | 305.80 |
| 2 | 22 | do | ......do | 271.40 |
| 2 | 23 | ......do | ......do | 353.70 |

*Abstract of disbursements made by John H. Renshawe, etc.*—Continued.

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1887. | | | | |
| Nov. 3 | 24 | J. E. Hill | Services, October | $30.00 |
| 5 | 25 | Riley & Corcoran | Hire horse, etc | 37.50 |
| 7 | 26 | A. L. Skeels | Hotel bill | 29.85 |
| 8 | 27 | S. S. Gannett | Traveling expenses | 15.65 |
| 8 | 28 | ......do | Field expenses | 133.51 |
| 13 | 29 | William J. Peters | Traveling expenses | 16.61 |
| 12 | 30 | C. T. Reid | ......do | 23.79 |
| 18 | 31 | M. J. Ryan | Hire self and team | 28.50 |
| 20 | 32 | William J. Peters | Field expenses | 119.25 |
| 26 | 33 | H. L. Baldwin | ......do | 45.35 |
| 26 | 34 | Van H. Manning, jr | Traveling expenses | 45.25 |
| 26 | 35 | W. E. Lackland | ......do | 47.60 |
| 26 | 36 | H. L. Baldwin, jr | ......do | 67.90 |
| 26 | 37 | George T. Hawkins | ......do | 49.45 |
| 26 | 38 | William H. Herron | ......do | 60.22 |
| 26 | 39 | Basil Duke | ......do | 35.25 |
| 26 | 40 | H. B. Blair | ......do | 35.00 |
| 26 | 41 | John H. Renshawe | ......do | 30.14 |
| 26 | 42 | ......do | Field expenses | 54.82 |
| 30 | 43 | H. H. Lee | Services, September 1 to October 16, 1887, inclusive. | 37.90 |
| Dec. 1 | 44 | J. P. Powell | Services, September 9 to October 15, 1887, inclusive. | 30.64 |
| 6 | 45 | Basil Duke | Services, November 1 to 30, 1887, inclusive. | 50.00 |
| 6 | 46 | H. B. Blair | Field expenses | 226.99 |
| 12 | 47 | J. H. Hagerty | Care of stock | 31.45 |
| 14 | 48 | Ernest M. Warren | Care of stock, etc | 64.00 |
| 15 | 49 | Ira M. Buell | Field expenses | 14.50 |
| 16 | 50 | C. T. Reid | Traveling expenses | 38.00 |
| 17 | 51 | J. Peach | Services, November 27 to December 3, 1887. | 14.00 |
| 17 | 52 | Frank Shanks | ......do | 14.00 |
| 17 | 53 | William J. Peters | Field expenses | 54.90 |
| 22 | 54 | ......do | Traveling expenses | 65.25 |
| 31 | 55 | ......do | Field expenses | 135.90 |
| 31 | 56 | C. T. Reid | Traveling expenses | 36.80 |
| 31 | 57 | ......do | Field expenses | 14.30 |
| 31 | 58 | Ernest M. Warren | Care of stock, etc | 64.00 |
| 31 | 59 | J. H. Hagerty | ......do | 25.00 |
| | | | | 5,468.78 |

*Abstract of disbursements made by G. K. Gilbert, disbursing agent, U. S. Geological Survey, during the fourth quarter of* 1887.

| | | | | |
|---|---|---|---|---|
| 1887. | | | | |
| Oct. 7 | 1 | G. K. Gilbert | Traveling expenses | $59.78 |
| 31 | 2 | ......do | Services, October, 1887 | 337.00 |
| Nov. 30 | 3 | ......do | Services, November, 1887 | 326.00 |
| Dec. 31 | 4 | ......do | Services, December, 1887 | 337.00 |
| | | | | 1,059.78 |

*Abstract of disbursements made by Jno. D. McChesney, chief disbursing clerk, U. S. Geological Survey, during the first quarter of* 1888.

| | | | | |
|---|---|---|---|---|
| 1888. | | | | |
| Jan. 12 | 1 | Z. D. Gilman | Photographic and laboratory supplies. | $150.61 |
| 13 | 2 | M. P. Felch | Services, November 1 to December, 31, 1887. | 250.00 |
| 13 | 3 | Robert Beall | Publications | 7.50 |
| 14 | 4 | H. O'Brien | Stationery | 19.00 |
| 16 | 5 | National Press Intelligence Company. | Newspaper clippings | 8.85 |
| 16 | 6 | Charles H. Kraft | Laboratory supplies | 23.46 |
| 16 | 7 | J. F. Sabin | Publications | 4.00 |
| 16 | 8 | W. H. Walmsley & Co | Photographic supplies | 3.75 |
| 16 | 9 | Missouri Pacific Railway Company. | Transportation of assistants | 92.70 |

*Abstract of disbursements made by Jno. D. McChesney, etc.*—Continued.

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1888. | | | | |
| Jan. 16 | 10 | Frank Sutton | Services, December, 1887 | $75.80 |
| 16 | 11 | Albert Williams, jr | ......do | 60.00 |
| 16 | 12 | ......do | Services, January, 1888 | 60.00 |
| 16 | 13 | George M. Turner | Services | 30.00 |
| 16 | 14 | Adams Express Company | Freight charges | 239.70 |
| 17 | 15 | Thomas C. Basshor & Co | Laboratory supplies | 4.08 |
| 17 | 16 | H. W. Johns Manufacturing Company. | ......do | 4.70 |
| 17 | 17 | Eimer & Amend | Laboratory material | 12.35 |
| 17 | 18 | Atchison, Topeka and Santa Fé Railroad. | Freight charges | 4.03 |
| 18 | 19 | J. B. Hatcher | Miscellaneous field expenses | 90.00 |
| 19 | 20 | Mutual District Messenger Company. | Rent of night watch | 5.30 |
| 19 | 21 | Pennsylvania Railroad Company. | Transportation of assistants | 19.20 |
| 19 | 22 | Eimer & Amend | Laboratory supplies | 24.20 |
| 19 | 23 | William Greenow | ......do | 88.00 |
| 19 | 24 | Wyckoff, Seamans & Benedict | Office furniture and repairs | 89.50 |
| 20 | 25 | Houghton, Mifflin & Co | Publications | 6.50 |
| 20 | 26 | C. W. Hayes | Services, December, 1887 | 50.00 |
| 20 | 27 | J. Karr | Repairs to office clocks | 10.00 |
| 20 | 28 | Joseph Thomas & Son | Office furniture | 95.00 |
| 21 | 29 | E. S. Boyd | Publications | 20.00 |
| 23 | 30 | C. W. Hall | Traveling expenses | 28.53 |
| 24 | 31 | Gottlieb Spitzer | Office furniture | 5.00 |
| 24 | 32 | A. M. Coyle | Instruments | 7.50 |
| 25 | 33 | J. B. Hatcher | Services, October 1 to December 31, 1887. | 480.00 |
| 26 | 34 | Warren Upham | Services, December, 1887 | 101.10 |
| 26 | 35 | Robert Boyd | Office and field supplies | 60.60 |
| 26 | 36 | George W. Knox | Freight charges and hauling | 48.16 |
| 31 | 37 | W. D. Heistand | Services, January, 1888 | 50.00 |
| 31 | 38 | W. S. Bayley | ......do | 60.00 |
| 31 | 39 | W. N. Merriam | ......do | 119.20 |
| 31 | 40 | Roland D. Irving | ......do | 255.50 |
| 31 | 41 | J. B. Hatcher | ......do | 160.00 |
| 31 | 42 | Samuel H. Scudder | ......do | 212.90 |
| 31 | 43 | Lawrence C. Johnson | ......do | 119.20 |
| 31 | 44 | O. C. Marsh | ......do | 340.70 |
| 31 | 45 | G. Baur | ......do | 140.00 |
| 31 | 46 | E. H. Barbour | ......do | 136.30 |
| 31 | 47 | F. Berger | ......do | 70.00 |
| 31 | 48 | L. P. Bush | ......do | 50.00 |
| 31 | 49 | J. Henry Blake | ......do | 153.30 |
| 31 | 50 | Frank Sutton | ......do | 76.60 |
| 31 | 51 | Walter L. Webb | ......do | 100.00 |
| 31 | 52 | Pay-roll of employés | ......do | 3,662.00 |
| 31 | 53 | ......do | ......do | 2,512.90 |
| 31 | 54 | ......do | ......do | 3,092.60 |
| 31 | 55 | ......do | ......do | 3,102.20 |
| 31 | 56 | ......do | ......do | 704.70 |
| 31 | 57 | ......do | ......do | 380.10 |
| 31 | 58 | George W. Shutt | ......do | 255.50 |
| Feb. 1 | 59 | Western Union Telegraph Company. | Telegrams | 3.91 |
| 1 | 60 | George Ryneal, jr | Office supplies, etc | 93.98 |
| 1 | 61 | E. E. Jackson & Co | Lumber | 38.53 |
| 1 | 62 | United States Express Company. | Freight charges | 76.25 |
| 1 | 63 | Wasuington Gas-Light Company. | Gas for January, 1888 | 129.77 |
| 1 | 64 | James Guild | Publications | 8.50 |
| 1 | 65 | Atchison, Topeka and Santa Fé Railroad. | Transportation of assistants | 113.55 |
| 1 | 66 | Gulf, Colorado and Santa Fé Railroad. | ......do | 37.80 |
| 1 | 67 | Pennsylvania Company | ......do | 52.50 |
| 1 | 68 | Arthur Keith | Services, January, 1888 | 50.00 |
| 1 | 69 | N. S. Shaler | ......do | 260.00 |
| 1 | 70 | Leo Lesquereux | ......do | 75.00 |
| 1 | 71 | James G. Bowen | Hire of horse and care of public animals. | 82.20 |
| 2 | 72 | B. F. McCaully & Co | Care of public animals | 27.50 |
| 3 | 73 | Charles D. Walcott | Services, January, 1888 | 170.30 |
| 3 | 74 | Charles S. Cudlip | Photographic supplies | 77.82 |
| 3 | 75 | William P. Rust | Services, January, 1888 | 58.50 |
| 3 | 76 | Ernest M. Warren | Care and forage of public animals | 64.00 |
| 4 | 77 | Wash. B. Williams | Office furniture | 69.25 |
| 4 | 78 | Wm. J. Park & Co | Stationery, etc | 8.19 |
| 4 | 79 | Kensington Engine Works | Laboratory supplies | 77.95 |
| 4 | 80 | Royce and Mareau | Electrical supplies | 3.90 |

*Abstract of disbursements made by Jno. D. McChesney, etc.*—Continued.

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1888. | | | | |
| Feb. 4 | 81 | Pay-roll of employés | Services, January, 1888 | $153.30 |
| 6 | 82 | Wyckoff, Seamans, & Benedict | Office supplies | 4.78 |
| 6 | 83 | Melville Lindsay | do | 6.27 |
| 6 | 84 | C. R. Van Hise | Services during January, 1888 | 65.00 |
| 6 | 85 | J. Park Channing | Services during December, 1887, January, 1888. | 30.00 |
| 6 | 86 | Collier Cobb | Services, January, 1888 | 50.00 |
| 7 | 87 | Albert Williams, jr | Services, January 16 to 31, 1888 | 70.00 |
| 7 | 88 | Lawrence C. Johnson | Traveling expenses | 32.25 |
| 8 | 89 | Photo. Engraving Company | Nine original drawings | 40.65 |
| 8 | 90 | Smedley Bros. & Co | Freight charges | 21.94 |
| 9 | 91 | C. W. Hayes | Services, January, 1888 | 50.00 |
| 10 | 92 | W. H. Lowdermilk & Co | Publications | 80.30 |
| 10 | 93 | Hannibal and St. Joseph Railroad | Transportation of assistants | 37.50 |
| 10 | 94 | Baltimore and Ohio Railroad | Freight charges | 11.59 |
| 13 | 95 | J. D. Free, jr | Publications | 25.15 |
| 13 | 96 | W. J. McGee | Traveling expenses | 136.70 |
| 15 | 97 | Missouri Pacific Railway Company. | Transportation of assistants | 37.56 |
| 17 | 98 | J. H. Hagerty | Care and forage of public animals | 25.00 |
| 17 | 99 | H. Rosendale | Making chisels | 10.20 |
| 17 | 100 | Rogers Steam Laundry | Laundrying towels | 2.04 |
| 17 | 101 | Capitol Steam Laundry | do | 1.09 |
| 20 | 102 | Western Union Telegraph Company. | Telegrams | 5.01 |
| 20 | 103 | R. S. Tarr | Services, November 7 to 30, 1887 | 21.00 |
| 21 | 104 | Albert Williams, jr | Services, February 1 to 21, 1888 | 90.00 |
| 23 | 105 | E. E. Jackson & Co | Office supplies and repairs | 51.24 |
| 23 | 106 | L. H. Schneider's Son | Office and laboratory supplies | 68.19 |
| 25 | 107 | Lawrence C. Johnson | Traveling expenses | 58.35 |
| 29 | 108 | Gustav E. Stechert | Publications | 189.03 |
| 29 | 109 | J. Bishop & Co | Chemical material | 41.31 |
| 29 | 110 | Roland D. Irving | Services, February, 1888 | 239.00 |
| 29 | 111 | Walter L. Webb | do | 100.00 |
| 29 | 112 | Samuel H. Scudder | do | 190.20 |
| 29 | 113 | Leo Lesquereux | do | 75.00 |
| 29 | 114 | Charles J. Cohen | Laboratory supplies | 22.60 |
| 29 | 115 | Henry A. Clarke & Son | Office supplies | 9.05 |
| 29 | 116 | M. W. Beveridge | Office furniture | 5.60 |
| 29 | 117 | Mutual District Messenger Company. | Rent of night watch | 5.00 |
| 29 | 118 | William H. Butler | Supplies, etc | 29.80 |
| 29 | 119 | Royce & Marean | Electrical supplies | 4.00 |
| 29 | 120 | Pay-roll of employés | Services, February, 1888 | 3,585.40 |
| 29 | 121 | do | do | 3,011.40 |
| 29 | 122 | do | do | 2,469.33 |
| 29 | 123 | do | do | 2,831.70 |
| 29 | 124 | do | do | 766.10 |
| 29 | 125 | do | do | 357.30 |
| 29 | 126 | George W. Shutt | do | 239.00 |
| Mar. 2 | 127 | John E. Ferguson | do | 57.40 |
| Feb. 29 | 128 | Arthur Keith | do | 50.00 |
| Mar. 1 | 129 | N. S. Shaler | do | 250.00 |
| 1 | 130 | J. Henry Blake | do | 143.40 |
| 1 | 131 | Washington Gas-Light Company | Gas for February, 1888 | 140.89 |
| 1 | 132 | David T. Day | Traveling expenses | 48.35 |
| 2 | 133 | James G. Bowen | Care and forage of public animals | 48.00 |
| 2 | 134 | J. B. Hatcher | Services, February, 1888 | 160.00 |
| 2 | 135 | G. Baur | do | 140.00 |
| 2 | 136 | H. Gibb | Services, January and February, 1888. | 120.00 |
| 2 | 137 | F. Berger | Services, February, 1888 | 70.00 |
| 2 | 138 | L. P. Bush | do | 50.00 |
| 3 | 139 | O. C. Marsh | do | 318.60 |
| 3 | 140 | W. N. Merriam | do | 111.60 |
| 3 | 141 | W. S. Bayley | do | 60.00 |
| 3 | 142 | William D. He stand | Services, January and February, 1888. | 50.00 |
| 3 | 143 | W. B. Clark | Services, February, 1888 | 90.00 |
| 5 | 144 | A. S. Witherbee & Co | Publications | 8.00 |
| 5 | 145 | do | do | 24.15 |
| 5 | 146 | do | do | 68.75 |
| 5 | 147 | W. H. Holmes | Traveling expenses | 45.80 |
| 5 | 148 | Robert Robertson | do | 17.51 |
| 5 | 149 | B. F. McCaully & Co | Care and forage of public animals | 27.00 |
| 7 | 150 | Adams Express Company | Freight charges | 113.85 |
| 7 | 151 | C. C. Vermeule | Pay, February, 1883 | 143.40 |
| 7 | 152 | J. H. Hagerty | Care and forage of public animals | 25.00 |
| 7 | 153 | Ernest M. Warren | do | 64.00 |

*Abstract of disbursements made by Jno. D. McChesney, etc.*—Continued.

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1888. | | | | |
| Mar. 7 | 154 | Frederick G. Rogers | Laundrying towels | $1.84 |
| 7 | 155 | Chicago and Alton Railroad | Transportation of assistants | 27.75 |
| 7 | 156 | Henry McShane & Co | Chemical supplies | 7.65 |
| 8 | 157 | C. W. Hayes | Services, February, 1888 | 50.00 |
| 8 | 158 | Hume, Cleary & Co | Photographic supplies | .38 |
| 8 | 159 | Franklin & Co | Laboratory supplies | .60 |
| 8 | 160 | Z. D. Gilman | do | 11.70 |
| 8 | 161 | do | Photographic and chemical supplies | 227.14 |
| 8 | 162 | James D. and E. S. Dana | Publications | 6.00 |
| 8 | 163 | Warren Upham | Services, February, 1888 | 95.60 |
| 8 | 164 | G. F. Wright | Services, July 1, 1887, to March 1, 1888. | 80.00 |
| 9 | 165 | Lewis G. Stevenson | Traveling expenses | 102.20 |
| 9 | 166 | Mutual District Messenger Company. | Rent of night watch | 5.00 |
| 9 | 167 | Robert M. Budd | Publications | 4.00 |
| 9 | 168 | Robert Boyd | Supplies for repairs | 60.63 |
| 10 | 169 | Charles S. Cudlip | Photographic supplies | 125.61 |
| 12 | 170 | Nat. K. Jones | Services, March 1 to 10, 1888 | 16.13 |
| 12 | 171 | The Unexcelled Fireworks Company. | Pasteboard tubes | 11.75 |
| 12 | 172 | August Frederick Foerste | Traveling expenses | 42.29 |
| 12 | 173 | William D. Castle | Field material and office repairs | 6.90 |
| 13 | 174 | A. J. Phinney | Services | 250.00 |
| 13 | 175 | N. S. Shaler | Traveling expenses | 76.05 |
| 13 | 176 | do | do | 46.10 |
| 13 | 177 | do | do | 223.20 |
| 14 | 178 | George Ryneal, jr | Photographic and office supplies | 12.25 |
| 14 | 179 | Henry Bufford | Services, November 1 to 11, 1887 | 15.00 |
| 14 | 180 | Henry A. Clarke & Son | Repairing caligraph | 8.50 |
| 14 | 181 | Pennsylvania Railroad Company | Transportation of assistants | 61.15 |
| 15 | 182 | John E. Ferguson | Services, March 1 to 11, 1888 | 21.76 |
| 16 | 183 | John F. Paret | Stationery and office supplies | 26.70 |
| 16 | 184 | H. Rosendale | Office supplies | 7.50 |
| 16 | 185 | James B. Lambie | do | 2.67 |
| 16 | 186 | Western Union Telegraph Company. | Telegrams | 1.91 |
| 16 | 187 | J. H. Mills & Co | Office supplies | 17.40 |
| 16 | 188 | Warren Upham | Services, January, 1888 | 102.20 |
| 16 | 189 | Albert Williams, jr | Services, February 22 to March 15, 1888. | 100.00 |
| 19 | 190 | E. E. Jackson & Co | Lumber | 53.85 |
| 19 | 191 | C. R. Van Hise | Services, February, 1888 | 65.00 |
| 19 | 192 | W. H. Walmsley & Co | Photographic material | 5.00 |
| 20 | 193 | Gayton A. Douglass & Co | Photographic supplies | 1.20 |
| 20 | 194 | Arthur Tomlin | Services | 5.00 |
| 22 | 195 | Atchison, Topeka and Santa Fé Railroad. | Transportation of assistants | 16.60 |
| 22 | 196 | William B. Phillips | Services | 50.00 |
| 30 | 197 | Earle Sloan | do | 150.00 |
| 31 | 198 | George W. Shutt | Services, March, 1888 | 255.50 |
| 31 | 199 | Pay-roll of employés | do | 3,832.30 |
| 31 | 200 | do | do | 3,007.40 |
| 31 | 201 | do | do | 2,574.30 |
| 31 | 202 | do | do | 3,102.90 |
| 31 | 203 | do | do | 581.70 |
| 31 | 204 | do | do | 382.60 |
| 31 | 205 | Ira Sayles | do | 119.20 |
| 31 | 206 | O. C. Marsh | do | 340.70 |
| 31 | 207 | E. H. Barbour | Services, February 1 to March 31, 1888. | 263.70 |
| 31 | 208 | William McAdams | Services, July 1, 1887, to January 31, 1888. | 275.00 |
| 31 | 209 | T. A. Bostwick | Services, January 1 to March 31, 1888. | 225.00 |
| 31 | 210 | A. Hermann | do | 225.00 |
| 31 | 211 | J. B. Hatcher | Services, March, 1888 | 200.00 |
| 31 | 212 | G. Baur | do | 140.00 |
| 31 | 213 | F. Berger | do | 70.00 |
| 31 | 214 | H. Gibb | do | 60.00 |
| 31 | 215 | L. P. Bush | do | 50.00 |
| 31 | 216 | Walter L. Webb | do | 100.00 |
| 31 | 217 | Roland D. Irving | do | 255.50 |
| 31 | 218 | Frank Burns | do | 85.20 |
| 31 | 219 | Sam H. Scudder | do | 212.90 |
| 31 | 220 | J. Henry Blake | do | 153.30 |
| 31 | 221 | Leo Lesquereux | do | 75.00 |
| 31 | 222 | C. C. Vermeule | do | 153.30 |
| 31 | 223 | N. S. Shaler | do | 270.00 |
| 31 | 224 | Arthur Keith | do | 50.00 |

*Abstract of disbursements made by Jno. D. McChesney, etc.*—Continued.

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1888. | | | | |
| Mar. 31 | 225 | Albert Williams, jr | Services, March 16 to 31, 1888 | $70.00 |
| 31 | 226 | E. H. Hill | Care and forage of public animals | 60.00 |
| 31 | 227 | Wyckoff, Seamans & Benedict | Repairs to typewriter | 42.00 |
| 31 | 228 | Charles D. Walcott | Traveling expenses | 14.25 |
| 31 | 229 | R. S. Tarr | ......do | 8.68 |
| 31 | 230 | W. N. Merriam | Services, March, 1888 | 119.20 |
| 31 | 231 | William D. Heistand | ......do | 50.00 |
| 31 | 232 | Robert Robertson | ......do | 60.00 |
| 31 | 233 | R. W. Westbrook | Services, January 1 to March 31, 1888. | 180.00 |
| 31 | 234 | V. F. Axtell | Care and forage of public animals | 172.20 |
| 31 | 235 | Roland D. Irving | Cash paid for freight, etc | 48.61 |
| 31 | 236 | Samuel P. Barbour | Storage of public property | 25.00 |
| 31 | 237 | Washington Gas-Light Company | Gas for March, 1888 | 122.76 |
| 31 | 238 | Washington City post-office | Rent of post-office boxes | 8.00 |
| 31 | 239 | Chicago, Rock Island and Pacific Railroad. | Transportation of assistants | 6.82 |
| 31 | 240 | J. D. Free, jr | Library supplies | 48.00 |
| 31 | 241 | I. P. Bishop | Atlas | 4.00 |
| 31 | 242 | James G. Bowen | Care and forage of public animals | 46.95 |
| 31 | 243 | Charles H. Kraft | Laboratory supplies | 27.80 |
| 31 | 244 | Chesapeake and Potomac Telephone Company. | Services, January 1 to March 31, 1888. | 155.50 |
| 31 | 245 | Great Falls Ice Company | Ice for January 1 to March 31, 1888. | 39.59 |
| | | | | 57,994.92 |

SALARIES, OFFICE OF GEOLOGICAL SURVEY.

| | | | | |
|---|---|---|---|---|
| 1888. | | | | |
| Jan. 31 | 1 | Pay-roll of employés | Services, January, 1888 | 3,026.50 |
| Feb. 29 | 2 | ......do | Services, February, 1888 | 2,832.00 |
| Mar. 31 | 3 | ......do | Services, March, 1888 | 3,026.50 |
| | | | | 8,885.00 |

*Abstract of disbursements made by C. D. Davis, special disbursing agent, U. S. Geological Survey, during the first quarter of* 1888.

| | | | | |
|---|---|---|---|---|
| 1888. | | | | |
| Jan. 5 | 1 | James H. Jennings | Traveling expenses | $16.86 |
| 14 | 2 | Sumner H. Bodfish | Miscellaneous field expenses | 38.89 |
| 31 | 3 | Pay-roll of employés | Services, January, 18 8 | 683.60 |
| | | | | 739.35 |

*Abstract of disbursements made by Mark B. Kerr, special disbursing agent, U. S. Geological Survey, during the first quarter of* 1888.

| | | | | |
|---|---|---|---|---|
| 1888. | | | | |
| Jan. 20 | 1 | E. M. Hasbrouck | Field expenses | $7.95 |
| 20 | 2 | A. H. Thompson | Traveling expenses | 189.83 |
| 20 | 3 | A. T. Kyle, jr | Pasturage, November, 1887 | 44.97 |
| 20 | 4 | ......do | Pasturage, December, 1887 | 45.95 |
| 20 | 5 | Litz D. Ermentrout | Services | 25.00 |
| 20 | 6 | Amos Scott | Pasturage, November and December, 1887. | 120.00 |
| 20 | 7 | Arthur P. Davis | Field expenses | 59.95 |
| 20 | 8 | A. P. Anderson | Pasturage | 4.52 |
| 20 | 9 | G. S. Howard | Storage | 6.00 |
| 20 | 10 | W. H. Scott | Pasturage | 46.00 |
| 31 | 11 | Pay-roll (office and field) | Services, January, 1888 | 2,384.80 |
| 31 | 12 | E. J. Owenhouse | Storage | 30.00 |
| Feb. 20 | 13 | Nephi Johnson | Services, December, 1887 | 60.00 |
| 20 | 14 | Charles W. Howell | Services, January, 1888 | 60.00 |
| 20 | 15 | A. T. Kyle, jr | Pasturage, etc., January, 1888 | 45.95 |
| 21 | 16 | Western Union Telegraph Company. | Telegrams | 9.72 |
| 29 | 17 | Pay-roll (office and field) | Services, February, 1888 | 2,097.00 |
| 29 | 18 | L. B. Putney | Forage | 54.00 |
| Mar. 22 | 19 | A. T. Kyle, jr | Pasturage and storage, February, 1888. | 45.95 |

*Abstract of disbursements made by Mark B. Kerr, etc.*—Continued.

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1888. | | | | |
| Mar. 31 | 20 | Charles W. Howell | Services, February and March, 1888. | $120.00 |
| 31 | 21 | Amos Scott | Services, January to March, 1888 | 180.00 |
| 31 | 22 | Nephi Johnson | Services, January, 1888 | 60.00 |
| 31 | 23 | ......do | Services, February and March, 1888. | 100.00 |
| 31 | 24 | J. T. Miller | Pasturage, January to March, 1888 | 82.50 |
| 31 | 25 | W. H. Scott | Pasturage | 69.00 |
| 31 | 26 | Pay-roll (office and field) | Services, March, 1888 | 2,231.50 |
| | | | | 8,180.59 |

*Abstract of disbursements made by P. H. Christie, special disbursing agent, U. S. Geological Survey, during the first quarter of* 1888.

| | | | | |
|---|---|---|---|---|
| 1888. | | | | |
| Jan. 20 | 1 | Sykes & Gwathmey | Maps | $5.00 |
| 31 | 2 | Pay-roll, January, 1888 | Services | 2,734.90 |
| 31 | 3 | W. F. Fling | Foraging of stock | 20.00 |
| 31 | 4 | E. M. Harnsberger | ......do | 50.00 |
| 31 | 5 | L. Morgan | ......do | 65.00 |
| 31 | 6 | N. B. Dunn | ......do | 166.50 |
| Feb. 21 | 7 | Thomas W. Sharrow | Field expenses | 43.80 |
| 23 | 8 | Gore, Janney & Co | Supplies | 3.25 |
| 29 | 9 | Pay-roll, February, 1888 | Services | 2,590.20 |
| 29 | 10 | W. T. Griswold | Traveling expenses | 14.95 |
| 29 | 11 | W. F. Fling | Forage of stock | 20.00 |
| 29 | 12 | E. M. Harnsberger | ......do | 50.00 |
| 29 | 13 | L. Morgan | ......do | 65.00 |
| 29 | 14 | N. B. Dunn | ......do | 166.50 |
| Mar. 15 | 15 | W. C. Holbrook | Field expenses | 12.50 |
| 31 | 16 | W. F. Fling | Forage of stock | 20.00 |
| 31 | 17 | E. M. Harnsberger | ......do | 50.00 |
| 31 | 18 | W. F. Latham | ......do | 108.00 |
| 31 | 19 | L. Morgan | ......do | 65.00 |
| 31 | 20 | Elias Foglesong | ......do | 10.50 |
| 31 | 21 | Z. N. Lockhart | ......do | 15.00 |
| 31 | 22 | J. G. Reeves | Forage of stock, etc | 94.50 |
| 31 | 23 | N. B. Dunn | Forage of stock | 166.50 |
| 31 | 24 | Pay-roll | Services, March, 1888 | 2,703.97 |
| | | | | 9,241.07 |

*Abstract of disbursements made by Arnold Hague, special disbursing agent, U. S. Geological Survey, during the first quarter of* 1888.

| | | | | |
|---|---|---|---|---|
| 1888. | | | | |
| Jan. 10 | 1 | E. J. Owenhouse | Storage | $15.00 |
| 31 | 2 | Pay-roll of employés | Salaries, January, 1888 | 755.30 |
| Feb. 6 | 3 | Charles H. Stuart | Pasturage | 106.83 |
| 17 | 4 | Francis C. Phillips | Analyses of gases | 75.00 |
| 29 | 5 | Pay-roll of employés | Salaries for February, 1888 | 714.40 |
| Mar. 6 | 6 | Joseph Hart | Services | 10.00 |
| 22 | 7 | Charles H. Stuart | Pasturage | 96.00 |
| 31 | 8 | Pay-roll of employés | Salaries, March, 1888 | 755.30 |
| | | | | 2,527.83 |

*Abstract of disbursements made by A. O. D. Taylor, jr., special disbursing agent, U. S. Geological Survey, during the first quarter of* 1888.

| | | | | |
|---|---|---|---|---|
| 1888. | | | | |
| Jan. 6 | 1 | Charles E. Hammett, jr | Stationery supplies | $3.85 |
| 31 | 2 | | (Disallowed.) | |
| 31 | 3 | Raphael Pumpelly | Pay for January, 1888 | 340.70 |
| 31 | 4 | T. Nelson Dale | ......do | 150.00 |
| 31 | 5 | A. O. D. Taylor, jr | ......do | 102.20 |
| 31 | 6 | H. L. Smyth | ......do | 85.20 |
| 31 | 7 | A. Prescott Baker | Rent | 50.00 |
| 31 | 8 | Newport Water Works | Six months' water rates | 9.00 |
| Feb. 2 | 9 | Adams Express Company | Express charges | 4.05 |
| 7 | 10 | Keuffel & Esser | Drawing materials | 15.41 |
| 7 | 11 | C. H. Codman & Co | Photographic supplies | 7.65 |

*Abstract of disbursements made by A. O. D. Taylor, jr., etc.*—Continued.

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1887. | | | | |
| Feb. 7 | 12 | H. L. Smyth | Traveling expenses | $3.75 |
| 8 | 13 | Eimer & Aurend | Photographic supplies | 6.60 |
| 8 | 14 | Scovill Manufacturing Company | ......do | 13.77 |
| 15 | 15 | Darling, Brown & Sharpe | One steel rule | 10.00 |
| 17 | 16 | Raphael Pumpelly | Incidental expenses | 45.54 |
| 20 | 17 | F. E. Swift | Board bill to October 3, 1887 | 90.50 |
| 24 | 18 | Newport Transfer Express Company | Freight and cartage | 4.44 |
| 29 | 19 | Raphael Pumpelly | Pay for February, 1888 | 318.60 |
| 29 | 20 | F. E. Swift | ......do | 95.60 |
| 29 | 21 | H. L. Smyth | ......do | 79.60 |
| 29 | 22 | T. Nelson Dale | ......do | 150.00 |
| 29 | 23 | A. Prescott Baker | Rent, February, 1888 | 50.00 |
| Mar. 2 | 24 | Richard Bliss | Bibliographical work | 36.00 |
| 2 | 25 | J. Eliot Wolff | Pay for January and February, 1888 | 98.90 |
| 8 | 26 | Benjamin French & Co | Photographic materials | 11.10 |
| 9 | 27 | Scovill Manufacturing Company | ......do | 13.25 |
| 10 | 28 | Raphael Pumpelly | Miscellaneous expenses | 53.86 |
| 10 | 29 | J. A. Williams | Services | 30.00 |
| 31 | 30 | Raphael Pumpelly | Pay for March, 1888 | 340.70 |
| 31 | 31 | H. L. Smyth | ......do | 85.20 |
| 31 | 32 | A. O. D. Taylor, jr | ......do | 102.20 |
| 31 | 33 | T. Nelson Dale | ......do | 150.00 |
| 31 | 34 | Richard Bliss | Bibliographical work | 21.90 |
| 31 | 35 | A. Prescott Baker | Rent for March, 1888 | 50.00 |
| 31 | 36 | C. H. Codman & Co | Photographic supplies | 8.87 |
| 31 | 37 | Frost & Adams | Drawing materials | 2.35 |
| | | | | 2,640.79 |

*Abstract of disbursements made by Fielding Burnes, disbursing agent, U. S. Geological Survey, during the first quarter of* 1888.

| | | | | |
|---|---|---|---|---|
| 1888. | | | | |
| Jan. 18 | 1 | E. W. F. Natter | Traveling expenses | $16.71 |
| 19 | 2 | William Kramer | ......do | 34.76 |
| 19 | 3 | ......do | Miscellaneous field expenses | 10.50 |
| 31 | 4 | William H. Lovell | Services, January, 1888 | 85.20 |
| 31 | 5 | Pay-roll of employés | ......do | 1,002.50 |
| Feb. 16 | 6 | William H. Lovell | Traveling expenses | 17.47 |
| 29 | 7 | Pay-roll of employés | Services, February, 1888 | 1,677.40 |
| Mar. 23 | 8 | Charles A. Putnam | ......do | 5.00 |
| 31 | 9 | Pay-roll of employés | Services, March, 1888 | 1,661.30 |
| | | | | 4,510.84 |

*Abstract of disbursements made by R. R. Hawkins, special disbursing agent, U. S. Geological Survey, during the first quarter of* 1888.

| | | | | |
|---|---|---|---|---|
| 1888. | | | | |
| Jan. 3 | 1 | Wemple Bros | Boxes | $22.50 |
| 3 | 2 | H. L. Howse | Supplies, etc | 3.18 |
| 4 | 3 | H. A. Messenger | Pasturing public animals | 32.45 |
| 5 | 4 | Albion S. Howe | Services, January 1 to 5, 1888, inclusive. | 10.00 |
| 10 | 5 | E. M. Sleator | Map | 1.50 |
| 10 | 6 | Postmaster | Box rent | 3.00 |
| 10 | 7 | Western Union | Telegrams | 3.94 |
| 12 | 8 | Wells, Fargo & Co | Expressage | 19.80 |
| 10 | 9 | Abner Doble | Hammers, etc | 5.00 |
| 10 | 10 | Frank Barnard & Co | Fuel | 5.95 |
| 10 | 11 | A. Carlisle & Co | Office supplies | 6.25 |
| 18 | 12 | W. S. Williams | Photographic supplies, etc | 17.00 |
| 31 | 13 | Pay-roll | Services, January, 1888 | 597.70 |
| 31 | 14 | E. A. Schneider | Services, January 6 to 31, inclusive, 1888. | 50.32 |
| Feb. 4 | 15 | H. A. Messenger | Pasturing public animals | 17.50 |
| Jan. 31 | 16 | G. W. Granniss | Rent of rooms | 52.66 |
| Feb. 11 | 17 | R. E. Morey | Boxes | 6.00 |
| 11 | 18 | S. F. Francis | Repairs | 8.50 |
| 23 | 19 | The California Electrical Works | Instruments | 30.00 |

*Abstract of disbursements made by R. R. Hawkins, etc.*—Continued.

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1888. | | | | |
| Feb. 24 | 20 | Samuel C. Partridge | Camera, lens, etc | $88.75 |
| 29 | 21 | Pay-roll | Services, February, 1888 | 559.60 |
| 29 | 22 | E. A. Schneider | do | 60.00 |
| 29 | 23 | G. W. Granniss | Rent of rooms | 52.66 |
| 29 | 24 | Main & Winchester | Tripod, case, etc | 33.35 |
| Mar. 2 | 25 | H. A. Messenger | Pasturing public animals | 17.50 |
| 9 | 26 | W. H. Melville | Traveling expenses | 66.30 |
| 13 | 27 | C. E. Watkins | Silver prints, etc | 4.75 |
| 13 | 28 | Frank Barnard & Co | Fuel | 4.00 |
| 13 | 29 | Abner Doble | Gas pipe | 3.00 |
| 15 | 30 | E. E. Ames | Open cart | 60.00 |
| 22 | 31 | John Taylor & Co | Laboratory supplies | 15.27 |
| 26 | 32 | G. W. Smethurst | Foraging public animals | 65.00 |
| 29 | 33 | Main & Winchester | Harness | 24.74 |
| 30 | 34 | I. C. Sawyer | Mule | 125.00 |
| 31 | 35 | Pay-roll | Services, March, 1888 | 597.70 |
| 31 | 36 | E. A. Schneider | do | 60.00 |
| 31 | 37 | G. W. Granniss | Rent of rooms | 52.66 |
| 31 | 38 | R. R. Hawkins | Sundry cash expenditures | 18.60 |
| | | | | 2,802.13 |

*Abstract of disbursements made by Alfred M. Rogers, disbursing agent, U. S. Geological Survey, during the first quarter of* 1888.

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1888. | | | | |
| Jan. 23 | 1 | Denver Gas Company | Laboratory material | $24.80 |
| 27 | 2 | George S. Turner | Transportation of property | 35.50 |
| 16 | 3 | Peter McCourt | Rent | 25.00 |
| 27 | 4 | L. G. Eakins | Traveling expenses | 46.50 |
| 31 | 5 | W. B. Smith | do | 65.90 |
| 31 | 6 | Kerthens & Peters | Transportation of property | 3.51 |
| 31 | 7 | James G. Kilpatrick | do | 52.00 |
| 31 | 8 | C. F. Bixby | do | .50 |
| 31 | 9 | Scott & Murch | do | 2.90 |
| 31 | 10 | Simon Hilker | do | 4.25 |
| 31 | 11 | Charles Jacobson | do | 3.75 |
| 31 | 12 | Samuel P. Barbee | Rent | 12.50 |
| 31 | 13 | Western Union Telegraph Company. | Correspondence | 3.17 |
| 31 | 14 | Wells, Fargo & Company's Express. | Transportation of property | 51.35 |
| 31 | 15 | George Linhart | do | 24.00 |
| 31 | 16 | William Wertman | Services | 6.00 |
| 31 | 17 | W. H. Lawrence & Co | Stationery | 8.20 |
| Feb. 14 | 18 | Alfred M. Rogers | Pay | 186.89 |
| 17 | 19 | C. Whitman Cross | Traveling expenses | 67.65 |
| | | | | 624.37 |

*Abstract of disbursements made by John D. McChesney, chief disbursing clerk, U. S. Geological Survey, during the second quarter of* 1888.

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1888. | | | | |
| Apr. 4 | 1 | B. F. McCaully & Co | Care and forage of public animals | $25.50 |
| 7 | 2 | William A. Raborg | Traveling expenses | 24.75 |
| 7 | 3 | Henry A. Fischer | Services | 6.00 |
| 9 | 4 | Warren Upham | Services, March, 1888 | 102.20 |
| 9 | 5 | C. R. Van Hise | do | 60.00 |
| 9 | 6 | United States Express Company | Freight charges | 21.75 |
| 9 | 7 | C. W. Hayes | Services, March, 1888 | 50.00 |
| 9 | 8 | L. C. Wooster | Services, January 2 to March 21, 1888 | 44.00 |
| 9 | 9 | George H. Williams | Services, January 1 to March 31, 1888 | 105.00 |
| 9 | 10 | I. Judell | Tollage | 21.65 |
| 9 | 11 | Adams Express Company | Freight | 27.95 |
| 11 | 12 | Shepherd & Hurley | Repairs to laboratory machinery | 2.70 |
| 11 | 13 | Mutual District Messenger Company. | Rent of night watch | 5.00 |
| 11 | 14 | Wash. B. Williams | Office furniture | 6.50 |
| 11 | 15 | Hume, Cleary & Co | Office supplies | 2.72 |
| 11 | 16 | William B. Clark | Services | 60.00 |

*Abstract of disbursements made by Jno. D. McChesney, etc.*—Continued.

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1888. | | | | |
| Apr. 11 | 17 | Baltimore and Ohio Railroad | Freight | $0.92 |
| 11 | 18 | ......do | ......do | 2.56 |
| 11 | 19 | ......do | ......do | 4.04 |
| 11 | 20 | C. Schneider | Laboratory material | 1.00 |
| 12 | 21 | Quartermaster's Department, U. S. Army. | Tent | 11.66 |
| 12 | 22 | E. Shaw | Services, August 28 to September 17, 1887. | 34.78 |
| 12 | 23 | Henry J. Green | Chemical material | 56.50 |
| 12 | 24 | William W. Walmsley & Co | Photographic supplies | 15.54 |
| 12 | 25 | Wyckoff, Seamans & Benedict | Stationery | 3.85 |
| 12 | 26 | Edward Kübel | Cash paid for repairs | 13.70 |
| 13 | 27 | James W. Queen & Co | Laboratory supplies | 29.17 |
| 13 | 28 | Julius Bien & Co | Copies of Geological and Topographical Atlas. | 466.25 |
| 13 | 29 | W. S. Bayley | Services, March 1 to 16, 1888 | 30.00 |
| 13 | 30 | John C. Parker | Office furniture | 89.00 |
| 14 | 31 | A. D. Duganne | Services, March, 1888 | 4.00 |
| 14 | 32 | Charles S. Cudlip | Photographic material | 97.58 |
| 14 | 33 | Henry O. Connor, jr | Services, March, 1888 | 12.00 |
| 16 | 34 | Julius Bien & Co | Copies of maps | 23.25 |
| 17 | 35 | F. W. Clarke | Traveling expenses | 7.75 |
| 17 | 36 | Pennsylvania Railroad Company | Transportation of assistants | 6.50 |
| 19 | 37 | S. J. Haislett | Rope | 1.20 |
| 23 | 38 | George Ryneal, jr | Artist materials, etc | 74.65 |
| 23 | 39 | Western Union Telegraph Company. | Telegrams | 2.41 |
| 23 | 40 | Harriet Biddle | Services, January 1 to March 31, 1888. | 30.00 |
| 23 | 41 | F. W. Stanton | Services, April 9 to 13, 1888 | 20.00 |
| 23 | 42 | ......do | Traveling expenses | 20.75 |
| 23 | 43 | J. H. Hagerty | Care and forage of public animals | 25.00 |
| 23 | 44 | William P. Rust | Services, February 1 to March 31, 1888. | 117.00 |
| 23 | 45 | Ernest M. Warren | Care and forage of public animals | 64.00 |
| 23 | 46 | Ollie McClain | Services in sewing desk covers | 4.26 |
| 23 | 47 | Unexcelled Fireworks Company | Stationery | 16.00 |
| 25 | 48 | L. Moxley | Chemical supplies | 10.80 |
| 25 | 49 | J. Karr | Laboratory supplies, etc | 5.00 |
| 25 | 50 | Julius Bien & Co | 250 copies of maps | 72.80 |
| 25 | 51 | E. S. Sperry | Services | 100.00 |
| 26 | 52 | Union Stone Company | Laboratory supplies | 37.10 |
| 26 | 53 | Faulk & Co | Instruments | 86.00 |
| 27 | 54 | J. H. Mills & Co | Type | 1.30 |
| 27 | 55 | M. W. Beveridge | Office supplies | 1.80 |
| 30 | 56 | Frank Burns | Services, April, 1888 | 82.40 |
| 30 | 57 | R. T. Hill | ......do | 98.90 |
| 30 | 58 | Sam. H. Scudder | ......do | 206.00 |
| 30 | 59 | J. Henry Blake | ......do | 148.30 |
| 30 | 60 | O. C. Marsh | ......do | 329.70 |
| 30 | 61 | J. B. Hatcher | ......do | 200.00 |
| 30 | 62 | G. Baur | ......do | 140.00 |
| 30 | 63 | F. Berger | ......do | 70.00 |
| 30 | 64 | H. Gibb | ......do | 60.00 |
| 30 | 65 | W. H. Burwell | ......do | 55.00 |
| 30 | 66 | O. A. Peterson | ......do | 55.00 |
| 30 | 67 | L. P. Bush | ......do | 50.00 |
| 30 | 68 | Leo Lesquereaux | ......do | 75.00 |
| 30 | 69 | Thomas Hampson | ......do | 126.37 |
| May 1 | 70 | Gore, Janney & Co | Office furniture | 86.00 |
| 1 | 71 | Robert T. Hill | Traveling expenses | 46.25 |
| 1 | 72 | Arthur Keith | Services, April, 1888 | 50.00 |
| 1 | 73 | Samuel H. Scudder | Cash paid for miscellaneous expenses. | 1.90 |
| 1 | 74 | Frank Leverett | Services, January 1 to March 31, 1888. | 390.00 |
| 1 | 75 | N. S. Shaler | Services, April, 1888 | 250.00 |
| 1 | 76 | Pederson & Olsen | Office furniture | 60.00 |
| Apr. 30 | 77 | Pay-roll of employés | Services, April, 1888 | 2,967.50 |
| 30 | 78 | ......do | ......do | 2,425.50 |
| 30 | 79 | ......do | ......do | 2,814.50 |
| 30 | 80 | ......do | ......do | 683.03 |
| 30 | 81 | ......do | ......do | 3,543.70 |
| 30 | 82 | ......do | ......do | 367.50 |
| 30 | 83 | George W. Shutt | ......do | 247.25 |
| 30 | 84 | Ira Sayles | ......do | 115.40 |
| May 1 | 85 | James G. Bowen | Care and forage of public animals | 46.45 |
| 1 | 86 | C. A. White | Traveling expenses | 134.80 |
| 3 | 87 | W. D. Heisland | Services during April, 1888 | 50.00 |
| 3 | 88 | W. N. Merriam | Services, April, 1888 | 115.40 |
| 3 | 89 | C. C. Vermule | ......do | 148.30 |

*Abstract af disbursements made by Jno. D. McChesney, etc.*—Continued.

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1888. | | | | |
| May 3 | 90 | C. B. Boyle | Traveling expenses | $106.55 |
| 3 | 91 | Z. D. Gilman | Laboratory and photographic supplies. | 374.80 |
| 3 | 92 | Washington Gas-Light Company. | Gas, April, 1888 | 109.51 |
| 3 | 93 | Denver and Rio Grande Railroad. | Freight charges | 14.81 |
| 3 | 94 | Baltimore and Ohio Railroad | ......do | 97.77 |
| 3 | 95 | Robert Robertson | Services, April, 1888 | 60.00 |
| 3 | 96 | Aug. F. Fouste | Services, January 1 to April 30, 1888. | 120.00 |
| 3 | 97 | J. B. Woodworth | ......do | 200.00 |
| 8 | 98 | R. C. Jones | Publication | 6.00 |
| 8 | 99 | J. and H. Berge | Chemical supplies | 6.45 |
| 8 | 100 | American Tool and Machine Company. | Laboratory material | 15.50 |
| 8 | 101 | J. H. Hagerty | Foraging animals | 25.00 |
| 8 | 102 | C. R. Van Hise | Services, April, 1888 | 60.00 |
| 8 | 103 | Warren Upham | ......do | 98.90 |
| 8 | 104 | Buffalo Dental Manufacturing Company. | Chemical supplies | 45.00 |
| 8 | 105 | Ernest M. Warren | Pasturage aud storage | 64.00 |
| 9 | 106 | B. F. McCaully & Co | Care and forage of public auimals | 26.50 |
| 7 | 107 | George Cartner | Publications | 7.00 |
| 8 | 108 | H. Hoffa | Chemical material | 5.00 |
| 10 | 109 | L. H. Schneider | Office and laboratory supplies | 131.13 |
| 10 | 110 | F. A. Brockhaus | Publications | 61.95 |
| 10 | 111 | Citizens' National Bank | Bill of exchange | 1.82 |
| 10 | 112 | R. S. Tarr | Traveling expenses | 26.13 |
| 10 | 113 | H. Rosendale | Geological hammers | 13.00 |
| 10 | 114 | Frank Burns | Traveling expenses | 140.12 |
| 11 | 115 | George W. Knox | Freight charges and hauling | 38.38 |
| 11 | 116 | E. E. Jackson & Co | Lumber | 86.61 |
| 11 | 117 | C. W. Hayes | Services, April, 1888 | 75.00 |
| 11 | 118 | Pennsylvania Railroad | Transportation of assistauts | 6.50 |
| 12 | 119 | Robert Leitch & Sons | Supplies | 49.32 |
| 12 | 120 | Eimer & Amend | Chemical supplies | 119.75 |
| 12 | 121 | ......do | Chemical supplies and material | 24.52 |
| 12 | 122 | The Educational Supply Company. | Chemical material | 31.62 |
| 12 | 123 | Mutual District Messenger Company. | Rental of night watch | 5.00 |
| 15 | 124 | Julius Bien & Co | 250 copies of maps | 90.75 |
| 15 | 125 | J. W. Powell | Traveling expenses | 39.81 |
| 15 | 126 | John F. Parett | Stationery, etc | 47.35 |
| 15 | 127 | John C. Parker | Repairs to type writer | 22.50 |
| 16 | 128 | Henry A. Clarke & Son | Repairs to caligraph | 4.00 |
| 16 | 129 | Charles D. Walcott | Traveling expenses | 39.72 |
| 17 | 130 | Roland D. Irving | Services, April, 1888 | 247.25 |
| 18 | 131 | David T. Day | Traveling expenses | 19.55 |
| 23 | 132 | L. H. Schneider's Son | Laboratory supplies, etc | 71.96 |
| 23 | 133 | W. M. Shuster & Sons | Map-mounting material | 38.63 |
| 23 | 134 | Hume, Cleary & Co. | Office supplies | 5.50 |
| 23 | 135 | Adams Express Company | Freight charges, March, 1888 | 43.10 |
| 23 | 136 | Western Union Telegraph Company. | Telegrams | 1.32 |
| 23 | 137 | M. W. Beveridge | Office furniture | 4.55 |
| 23 | 138 | Adams Express Company | Freight charges, April, 1888 | 61.35 |
| 23 | 139 | Alabama Great Southern Railroad. | Transportation of assistants | 5.40 |
| 24 | 140 | John R. Proctor | Services, November 2, 1887, to May 24, 1888. | 200.00 |
| 25 | 141 | C. S. Cudlip | Laboratory and photographic supplies. | 323.28 |
| 25 | 142 | William P. Rust | Services, April, 1888 | 56.25 |
| 26 | 143 | Wyckoff, Seamans & Benedict | Office furniture, etc | 87.50 |
| 28 | 144 | Thomas Somerville & Co | Photographic material | 15.50 |
| 31 | 145 | F. F. Chisolm | Services | 225.00 |
| 31 | 146 | Charles H. Kraft | Chemical supplies | 41.92 |
| 31 | 147 | J. Henry Blake | Services, May, 1888 | 153.40 |
| 31 | 148 | Sam H. Scudder | ......do | 213.00 |
| 31 | 149 | Robert T. Hill | ......do | 102.20 |
| 31 | 150 | Frank Leverett | ......do | 220.00 |
| 31 | 151 | Leo Lesquereaux | ......do | 75.00 |
| 31 | 152 | N. S. Shaler | ......do | 270.00 |
| 31 | 153 | Robert Robertsou | ......do | 60.00 |
| 31 | 154 | Roland D. Irving | ......do | 247.25 |
| 31 | 155 | O. C. Marsh | ......do | 340.60 |
| 31 | 156 | J. B. Hatcher | ......do | 200.00 |
| 31 | 157 | G. Baur | ......do | 140.00 |
| 31 | 158 | F. Berger | ......do | 70.00 |
| 31 | 159 | H. Gibb | ......do | 60.00 |

*Abstract of disbursements made by Jno. D. McChesney, etc.*—Continued.

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1888. | | | | |
| May 31 | 160 | W. H. Burwell | Services, May, 1888 | $55.00 |
| 31 | 161 | O. A. Peterson | ......do | 55.00 |
| 31 | 162 | L. P. Bush | ......do | 50.00 |
| 31 | 163 | C. Willard Hayes | ......do | 75.00 |
| 31 | 164 | Aloysius B. Renehan | ......do | 30.00 |
| 31 | 165 | Arthur Keith | ......do | 50.00 |
| 31 | 166 | George W. Shutt | ......do | 255.50 |
| 31 | 167 | Ira Sayles | ......do | 119.20 |
| 31 | 168 | Pay-roll of employés | ......do | 2,735.40 |
| 31 | 169 | ......do | ......do | 3,833.00 |
| 31 | 170 | ......do | ......do | 2,469.20 |
| 31 | 171 | ......do | ......do | 3,109.00 |
| 31 | 172 | ......do | ......do | 741.60 |
| 31 | 173 | ......do | ......do | 382.50 |
| June 2 | 174 | William P. Rust | ......do | 67.50 |
| 2 | 175 | James G. Bowen | Care and forage of public animals | 47.00 |
| 2 | 176 | Washington Gas-Light Company | Gas for May, 1888 | 85.39 |
| 4 | 177 | Gilbert A. Ayars | Services, March 1 to May 31, 1888 | 6.00 |
| 4 | 178 | George E. Ladd | Services, April 1 to 15, 1888 | 24.00 |
| 4 | 179 | J. B. Woodward | Services, May, 1888 | 50.00 |
| 4 | 180 | W. J. McGee | ......do | 204.40 |
| 4 | 181 | Hall & Sons | Chemical supplies | 28.50 |
| 4 | 182 | Charles H. Kraft | ......do | 23.05 |
| 7 | 183 | B. F. McCaully & Co | Care and forage of public animals | 26.50 |
| 7 | 184 | George N. Rider | Publications | 7.00 |
| 7 | 185 | C. A. White | Traveling expenses | 101.15 |
| 7 | 186 | C. C. Vermeule | ......do | 15.60 |
| 7 | 187 | ......do | Services, May 1 to June 6, 1888 | 183.07 |
| 7 | 188 | Alfred M. Rogers | Services, February 15 to 29, 1888 | 61.81 |
| 7 | 189 | Andrew T. Manley | Services, June 1 to 6, 1888 | 10.00 |
| 7 | 190 | J. H. Hagerty | Care and forage of public animals | 25.00 |
| 7 | 191 | W. W. Meldrum | Supplies for repairs of instruments | 6.00 |
| 7 | 192 | Eimer & Amend | Chemical supplies | 47.15 |
| 12 | 193 | Robert Boyd | Office supplies | 41.69 |
| 12 | 194 | Mutual District Messenger Company | Rental of night watch | 5.00 |
| 12 | 195 | Edward J. Hannan | Repairs to laboratory | 9.00 |
| 12 | 196 | W. M. Shuster & Sons | Office supplies | 2.81 |
| 12 | 197 | Wyckoff, Seamans & Benedict | Repairs to typewriter | 5.25 |
| 12 | 198 | J. Karr | Supplies for repairs of instruments | 2.50 |
| 12 | 199 | Baltimore and Ohio Railroad Company | Transportation of assistants | 71.65 |
| 12 | 200 | ......do | ......do | 356.75 |
| 9 | 201 | F. W. Geiger | Traveling expenses | 18.50 |
| 11 | 202 | John C. Parker | Supplies for repairs, etc | 8.50 |
| 12 | 203 | Emil Jonscher | Repairs and supplies for instruments | 78.20 |
| 12 | 204 | S. M. Youngs | Publications | 4.00 |
| 12 | 205 | R. S. Tarr | Traveling expenses | 23.79 |
| 13 | 206 | James B. Lambie | Material for modeling purposes | 7.16 |
| 13 | 207 | H. Rosendale | Repairing chisels | .75 |
| 13 | 208 | Z. D. Gilman | Photographic supplies | 371 66 |
| 13 | 209 | Robert Stern | Traveling expenses | 9.25 |
| 14 | 210 | R. R. Bowker | Publications | 14.75 |
| 14 | 211 | George H. Cook | Cash paid for hauling | 3.00 |
| 14 | 212 | Newport News and Mississippi Railroad | Transportation of assistants | 20.45 |
| 15 | 213 | Z. D. Gilman | Laboratory supplies | 11.70 |
| 15 | 214 | M. W. Beveridge | Field material | 17.00 |
| 16 | 215 | Easton & Rupp | Stationery | 13.05 |
| 16 | 216 | George H. Williams | Services, April 1 to June 1, 1888 | 55.00 |
| 16 | 217 | W. B. Moses & Son | Office furniture | 1.50 |
| 16 | 218 | Richmond and Danville Railroad | Transportation of assistants | 94.70 |
| 16 | 219 | Ernest M. Warren | Care and forage of public animals | 64.00 |
| 19 | 220 | J. W. Powell | Traveling expenses | 26.25 |
| 19 | 221 | Carroll Webster | ......do | 4.60 |
| 19 | 222 | N. P. Jones | Making photograph prints | 12.24 |
| 19 | 223 | William D. Heistand | Services, May 1 to 31, 1888 | 50.00 |
| 19 | 224 | W. J. McGee | Traveling expenses | 77.72 |
| 19 | 225 | W. N. Merriam | Services, May, 1888 | 119.20 |
| 19 | 226 | Samuel L. Penfield | Services, October 6, 1887, to May 31, 1888. | 100.00 |
| 19 | 227 | W. F. Hillebrand | Traveling expenses | 57.73 |
| 20 | 228 | George Ryneal, jr | Office supplies, etc | 36.75 |
| 20 | 229 | United States Express | Freight | 24.35 |
| 20 | 230 | C. B. Atkinson | Lining tank, etc | 12.00 |
| 22 | 231 | E. E. Jackson & Co | Lumber | 140.68 |
| 22 | 232 | Oregon and California Railroad | Transportation of assistants | 13.68 |
| 22 | 233 | R. L. Bryant | 1 horse | 150.00 |

*Abstract of disbursements made by Jno. D McChesney, etc.*—Continued.

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1888. | | | | |
| June 22 | 234 | James W. Queen & Co | Chemical supplies | $43.52 |
| 22 | 235 | Eric Noble | Services | 25.00 |
| 22 | 236 | James M. Swank | ......do | 300.00 |
| 22 | 237 | Western Union Telegraph Company. | Telegrams | 7.95 |
| 23 | 238 | W. D. Castle | Field material | 18.75 |
| 25 | 239 | F. W. Clarke | Traveling expenses | 22.56 |
| 25 | 240 | William H. Dall | ......do | 18.64 |
| 26 | 241 | Shepherd & Hurley | Laboratory supplies | 4.40 |
| 26 | 242 | John Birkenbine | Services | 100.00 |
| 26 | 243 | Robert Robertson | Traveling expenses | 47.35 |
| 26 | 244 | James C. Hooe | Services during September 1, 1887, to June 15, 1888. | 20.00 |
| 27 | 245 | George W. Knox | Freight | 8.86 |
| 27 | 246 | C. Willard Hayes | Traveling expenses | 17.51 |
| 27 | 247 | Amos E. Woodward | ......do | 11.00 |
| 27 | 248 | Oregon and California Railroad | Transportation of assistants | 1.79 |
| 28 | 249 | Adams Express Company | Freight charges | 142.00 |
| 28 | 250 | Evening Star Newspaper Company. | Field supplies | 1.50 |
| 28 | 251 | James S. Topham | Office supplies and repairs | 14.00 |
| 28 | 252 | Henry J. Biddle | Services | 100.00 |
| 30 | 253 | Northern Pacific Railroad | Transportation of assistants | 180.45 |
| 29 | 254 | Baltimore and Potomac Railroad. | Freight charges | 4.52 |
| 30 | 255 | Z. N. Lockhart | 1 horse | 165.00 |
| 30 | 256 | Collier Cobb | Services, June, 1888 | 50.00 |
| 30 | 257 | Robert Robertson | ......do | 60.00 |
| 30 | 258 | Bailey Willis | ......do | 197.80 |
| 30 | 259 | Robert T. Hill | ......do | 98.90 |
| 30 | 260 | W. J. McGee | ......do | 197.80 |
| 30 | 261 | I. C. Russell | ......do | 164.29 |
| 30 | 262 | Charles D. Walcott | ......do | 197.80 |
| 30 | 263 | Ira Sayles | ......do | 115.40 |
| 30 | 264 | Lawrence C. Johnson | ......do | 115.40 |
| 30 | 265 | C. Willard Hayes | ......do | 74.20 |
| 30 | 266 | Pay-roll of employés | ......do | 3,708.50 |
| 30 | 267 | ......do | ......do | 3,024.00 |
| 30 | 268 | ......do | ......do | 1,990.50 |
| 30 | 269 | ......do | ......do | 2,370.20 |
| 30 | 270 | ......do | ......do | 639.36 |
| 30 | 271 | ......do | ......do | 370.00 |
| 30 | 272 | George W. Shutt | ......do | 247.25 |
| 30 | 273 | Inman E. Morgan | ......do | 19.50 |
| 30 | 274 | O. C. Marsh | ......do | 329.70 |
| 30 | 275 | E. H. Barbour | Services, April 1 to June 30, 1888 | 400.00 |
| 30 | 276 | T. A. Bostwick | ......do | 225.00 |
| 30 | 277 | A. Hermann | ......do | 225.00 |
| 30 | 278 | H. Gibb | Services, June, 1888 | 60.00 |
| 30 | 279 | C. S. Cudlip | Photographic supplies | 432.32 |
| 30 | 280 | Alfred M. Rogers | Cash paid for freight | 5.53 |
| 30 | 281 | Samuel P. Barbee | Rent of store-room | 37.50 |
| 30 | 282 | E. H. Hill | Care and forage of public animals | 34.00 |
| 30 | 283 | R. L. Packard | Services, January 2 to June 11, 1888 | 115.00 |
| 30 | 284 | Pay-roll of employés | Services, June, 1888 | 81.49 |
| 30 | 285 | Sam H. Scudder | ......do | 206.00 |
| 30 | 286 | Frank Sutton | ......do | 74.20 |
| 30 | 287 | Leo Lesquereaux | ......do | 75.00 |
| 30 | 288 | Eastman Dry Plate and Film Company. | Photographic supplies | 18.00 |
| 30 | 289 | C. R. Van Hise | Services, May 1 to June 30, 1888 | 190.00 |
| 30 | 290 | L. C. Lohman | Storage of Government property | 4.25 |
| 30 | 291 | R. S. Tarr | Services, June, 1888 | 50.00 |
| 30 | 292 | Aug. F. Foerste | ......do | 50.00 |
| 30 | 293 | J. Henry Blake | ......do | 148.30 |
| 30 | 294 | C. R. Van Hise | Traveling expenses | 43.67 |
| 30 | 295 | James G. Bowen | Care and forage of public animals | 68.25 |
| 30 | 296 | Aloysius B. Renehan | Services, June, 1888 | 30.00 |
| 30 | 297 | Pay-roll of employés | ......do | 123.50 |
| 30 | 298 | Mutual District Messenger Company. | Rental of night watch | 5.00 |
| 30 | 299 | Arthur Keith | Traveling expenses | 53.10 |
| 30 | 300 | Bailey Willis | ......do | 19.95 |
| 30 | 301 | C. Willard Hayes | Cash paid for expenses | 76.88 |
| 20 | 302 | Chesapeake and Potomac Telephone Company. | Services, April 1 to June 30, 1888 | 155.50 |
| 30 | 303 | B. F. McCaully & Co | Care and forage of public property | 13.25 |
| 30 | 304 | C. L. Moulton | Veterinary services | 20.00 |
| 30 | 305 | Washington Gas-Light Company. | Gas for June, 1888 | 78.89 |

*Abstract of disbursements made by Jno. D McChesney, etc.*—Continued.

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1888. | | | | |
| June 30 | 306 | W. H. Holmes | Traveling expenses | $39.05 |
| 30 | 307 | Edward Kübel | Miscellaneous expenses | 9.17 |
| 30 | 308 | Ernest M. Warren | Care and forage of public property | 64.00 |
| 30 | 309 | J. H. Hagerty | ......do | 25.00 |
| 30 | 310 | Warren Upham | Services, May, 1888 | 102.20 |
| 30 | 311 | ......do | Services, June, 1888 | 98.90 |
| 30 | 312 | William P. Rust | ......do | 65.00 |
| 30 | 313 | N. S. Shaler | ......do | 260.00 |
| 30 | 314 | Williams & Co | Specimens | 10.50 |
| 30 | 315 | S. J. Haislett | Field material | 21.00 |
| 30 | 316 | Fred. A. Schmidt | Publications | 4.00 |
| 30 | 317 | Unexcelled Fire-works Company | Mailing tubes, etc | 21.50 |
| 30 | 318 | Wyckoff, Seamans & Benedict | Office supplies | 4.17 |
| 30 | 319 | W. B. Taylor | Field supplies | 44.74 |
| 30 | 320 | Keuffel & Esser | Drawing material | 25.20 |
| 30 | 321 | Arthur Keith | Field expenses | 27.50 |
| 30 | 322 | Lutz & Bro | Field supplies | 1.25 |
| 30 | 323 | Z. D. Gilman | Laboratory and photographic supplies. | 87.96 |
| 30 | 324 | W. C. Day | Services, January 2 to June 30, 1888 | 170.00 |
| 30 | 325 | Lansburgh & Bro | Office supplies | .75 |
| 30 | 326 | Hume, Cleary & Co | Photographic supplies | .40 |
| 30 | 327 | Great Falls Ice Company | Ice, April 1 to June 30, 1888 | 41.50 |
| 30 | 328 | National Press Intelligence Company, | Furnishing newspaper clippings | 24.05 |
| 30 | 329 | W. N. Merriam | Services, June, 1888 | 115.40 |
| 30 | 330 | William D. Heistand | ......do | 50.00 |
| 30 | 331 | C. W. Nall | Services, January 1 to June 30, 1888 | 112.50 |
| | | | | 61,390.32 |

SALARIES, OFFICE OF GEOLOGICAL SURVEY.

| | | | | |
|---|---|---|---|---|
| 1888. | | | | |
| Apr. 30 | 1 | Pay-roll of employés | Services, April, 1887 | 2,855.15 |
| May 31 | 2 | ......do | Services, May, 1887 | 2,949.70 |
| June 30 | 3 | ......do | Services, June, 1887 | 2,855.15 |
| | | | | 8,660.00 |

*Abstract of disbursements made by C. D. Davis, special disbursing agent, U. S. Geological Survey, during the second quarter of* 1888.

| | | | | |
|---|---|---|---|---|
| 1888. | | | | |
| May 12 | 1 | R. M Towson | Field expenses | $21.35 |
| 12 | 2 | W. R. Atkinson | ......do | 18.50 |
| 22 | 3 | ......do | ......do | 32.50 |
| 26 | 4 | R. M. Towson | ......do | 31.98 |
| 28 | 5 | E. C. Robinson | Transportation | 68.64 |
| 31 | 6 | W. R. Atkinson | Field expenses | 25.00 |
| 31 | 7 | W. H. Lovell | Services, May, 1888 | 85.20 |
| 31 | 8 | Lawrence Thompson | ......do | 85.20 |
| June 1 | 9 | W. D. Johnson | Field expenses | 5.70 |
| 6 | 10 | W. R. Atkinson | ......do | 26.50 |
| 12 | 11 | R. M. Thompson | ......do | 35.28 |
| 13 | 12 | W. R. Atkinson | ......do | 20.25 |
| 21 | 13 | ......do | ......do | 18.15 |
| May 31 | 14 | Fielding Burnes | Services, May, 1888 | 153.40 |
| June 26 | 15 | Robert D. Cummin | Traveling expenses | 12.10 |
| 26 | 16 | Lawson Sandford | ......do | 13.60 |
| 27 | 17 | W. R. Atkinson | Field expenses | 32.80 |
| 30 | 18 | Pay-roll of employés | Services, June, 1888 | 1,631.90 |
| 30 | 19 | R. H. Hale | ......do | 75.00 |
| 30 | 20 | C. C. Bassett | Traveling expenses | 12.12 |
| 30 | 21 | James Longstreet | ......do | 12.12 |
| 30 | 22 | C. C. Bassett | Field expenses | 51.12 |
| 30 | 23 | E. G. Kennedy | Traveling expenses | 10.25 |
| 30 | 24 | R. D. Cummin | Field expenses | 34.66 |
| 30 | 25 | C. C. Bassett | Traveling expenses | 7.40 |
| | | | | 2,520.72 |

*Abstract of disbursements made by Mark B. Kerr, disbursing agent, U. S. Geological Survey, during the second quarter of* 1888.

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1888. | | | | |
| Apr. 30 | 1 | Pay-roll (office and field) | Services, April, 1888 | $2,164.20 |
| May 31 | 2 | ......do | Services, May, 1888 | 1,627.00 |
| June 4 | 3 | E. M. Douglas | Field expenses | 42.67 |
| 4 | 4 | ......do | Traveling expenses | 51.50 |
| 4 | 5 | Frank Tweedy | ......do | 51.75 |
| 4 | 6 | A. Lamme & Co | Subsistence supplies | 87.09 |
| 4 | 7 | E. J. Owenhouse | Repairs | 13.40 |
| 4 | 8 | Jones & Koch | Field supplies | 18.50 |
| 4 | 9 | H. M. Wilson | Field expenses | 61.42 |
| May 31 | 10 | E. T. Perkins, jr | Traveling expenses | 51.85 |
| June 6 | 11 | Pay-roll (E. M. Douglas) | Services, May, 1888 | 219.82 |
| 6 | 12 | Amos Scott | Services, April 1 to May 15, 1888, inclusive. | 90.00 |
| 6 | 13 | Highsmith, Beam and Winter | Field expenses | 61.60 |
| 14 | 14 | Redick H. McKee | ......do | 40.65 |
| 14 | 15 | ......do | ......do | 74.15 |
| 14 | 16 | Frank Tweedy | ......do | 25.90 |
| 14 | 17 | Paul Holman | ......do | 10.25 |
| 19 | 18 | A. F. Dunnington | ......do | 40.55 |
| 19 | 19 | ......do | ......do | 19.35 |
| 25 | 20 | Redick H. McKee | ......do | 115.75 |
| 25 | 21 | W. T. Griswold | ......do | 43.65 |
| 25 | 22 | Hecla Mercantile and Banking Company. | Subsistence, etc | 28.65 |
| 25 | 23 | C. S. Winsor | Field subsistence, etc | 49.60 |
| 25 | 24 | F. G. Pratt & Co | Subsistence, etc | 19.99 |
| 25 | 25 | Highsmith, Beam, & Winter | Field expenses | 8.00 |
| 25 | 26 | Charles Baker | ......do | 12.00 |
| 30 | 27 | Pay-roll (Dunnington) | Services, June, 1888 | 274.43 |
| 30 | 28 | Pay-roll (Griswold) | ......do | 293.30 |
| 30 | 29 | Pay-roll (Wilson) | ......do | 427.20 |
| 30 | 30 | Pay-roll (office and field) | ......do | 768.10 |
| 30 | 31 | R. H. Chapman | ......do | 82.40 |
| 30 | 32 | A. H. Thompson | ......do | 222.50 |
| 30 | 33 | Mark B. Kerr | ......do | 148.30 |
| 30 | 34 | Pay-roll (Perkins) | ......do | 232.40 |
| 30 | 35 | Pay-roll (Tweedy) | ......do | 336.90 |
| 30 | 36 | Pay-roll (Douglas) | ......do | 364.80 |
| | | | | 8,179.62 |

*Abstract of disbursements made by P. H. Christie, special disbursing agent, U. S. Geological Survey, during the second quarter of* 1888.

| | | | | |
|---|---|---|---|---|
| 1888. | | | | |
| Apr. 30 | 1 | Pay-roll | Services, April, 1888 | $2,612.10 |
| 30 | 2 | W. F. Fling | Forage of stock | 20.00 |
| 30 | 3 | E. M. Harnsberger | ......do | 50.00 |
| 30 | 4 | L. Morgan | ......do | 65.00 |
| 30 | 5 | N. B. Dunn | ......do | 166.50 |
| May 11 | 6 | L. D. Brent | Miscellaneous field expenses | 30.50 |
| 11 | 7 | Charles M. Yeates | ......do | 5.30 |
| 11 | 8 | L. D. Brent | Traveling expenses | 9.25 |
| 11 | 9 | Charles M. Yeates | ......do | 15.50 |
| 11 | 10 | A. E. Wilson | ......do | 28.00 |
| Apr. 30 | 11 | H. H. Snyder | Storage of survey property | 2.75 |
| May 17 | 12 | R. O. Gordon | Traveling expenses | 5.25 |
| 17 | 13 | F. B. Riley | Subsistence and forage | 21.65 |
| 24 | 14 | Charles M. Yeates | Miscellaneous field expenses | 25.69 |
| 24 | 15 | George Jackson | Services, May 8 to 14, 1888 | 7.00 |
| 24 | 16 | Faris & Co | Subsistence supplies | 57.75 |
| 25 | 17 | George E. Kennedy & Son | ......do | 8.10 |
| 31 | 18 | J. W. Hays | Services, May, 1888 | 102.20 |
| 31 | 19 | Pay-roll | ......do | 286.80 |
| 31 | 20 | ......do | ......do | 2,214.60 |
| 31 | 21 | ......do | ......do | 151.69 |
| 31 | 22 | R. Lee Longstreet | Traveling expenses | 65.00 |
| 31 | 23 | W. F. Fling | Forage of stock | 10.00 |
| 31 | 24 | E. M. Harnsberger | ......do | 50.00 |
| 31 | 25 | F. J. Chapman | ......do | 26.00 |
| 31 | 26 | N. B. Dunn | Forage of stock, etc | 86.20 |
| June 4 | 27 | R. O. Gordon | Miscellaneous field expenses | 51.94 |
| 7 | 28 | Charles M. Yeates | ......do | 97.85 |
| 8 | 29 | E. C. Barnard | Traveling expenses | 9.20 |
| 8 | 30 | ......do | Miscellaneous field expenses | 54.75 |
| 20 | 31 | A. E. Murlin | Traveling expenses | 2.25 |

*Abstract of disbursements made by P. H. Christie, etc.*—Continued.

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1888. | | | | |
| June 22 | 32 | Charles M. Yeates | Miscellaneous field expenses | $58.30 |
| 25 | 33 | H. Reaves | Field material | 12.50 |
| 30 | 34 | Pay-roll | Services, June, 1888 | 283.30 |
| 30 | 35 | ......do | ......do | 281.60 |
| 30 | 36 | J. W. Hays | ......do | 98.90 |
| 30 | 37 | N. B. Dunn | Forage of stock | 87.67 |
| 30 | 38 | Elias Foglesong | ......do | 7.50 |
| 30 | 39 | Z. N. Lockhart | ......do | 10.50 |
| 30 | 40 | W. F. Latham | ......do | 87.00 |
| 30 | 41 | F. J. Chapman | ......do | 26.00 |
| 30 | 42 | E. M. Harnsberger | ......do | 50.00 |
| 30 | 43 | J. G. Reaves | ......do | 39.05 |
| 30 | 44 | Pay-roll | Services, June, 1888 | 2,001.90 |
| 30 | 45 | Henkel & Corpening | Storage | 6.00 |
| 30 | 46 | William C. Holbrook | ......do | 16.00 |
| 30 | 47 | W. H. Jackson & Co | ......do | 20.00 |
| 30 | 48 | D. P. Grinnell and R. N. Worwock. | ......do | 15.13 |
| 30 | 49 | W. F. Fling | Forage of stock | 10.00 |
| 30 | 50 | R. O. Gordon | Miscellaneous field expenses | 56.08 |
| 30 | 51 | M. S. Fowler | Storage of survey property | 6.00 |
| 30 | 52 | Charles M. Yeates | Miscellaneous field expenses | 63.35 |
| 30 | 53 | P. H. Christie | Traveling expenses | 62.15 |
| 30 | 54 | J. W. Hays | ......do | 18.00 |
| 30 | 55 | ......do | Miscellaneous field expenses | 83.45 |
| 30 | 56 | ......do | ......do | 78.79 |
| 30 | 57 | F. P. Gulliver | ......do | 51.10 |
| 30 | 58 | ......do | ......do | 21.30 |
| 30 | 59 | A. E. Murlin | ......do | 22.35 |
| 30 | 60 | F. P. Gulliver | Traveling expenses | 11.27 |
| 30 | 61 | S. J. Haislett | Field material | 72.00 |
| 30 | 62 | V. Schoonmaker | ......do | 300.00 |
| 30 | 63 | M. Hackett | Traveling expenses | 3.62 |
| 30 | 64 | V. Schoonmaker | Field expenses | 75.00 |
| 30 | 65 | M. Hackett | Miscellaneous field expenses | 36.27 |
| | | | | 10,411.90 |

*Abstract of disbursements made by Arnold Hague, special disbursing agent, U. S. Geological Survey, during the second quarter of* 1888.

| | | | | |
|---|---|---|---|---|
| 1888. | | | | |
| Apr. 4 | 1 | E. J. Owenhouse | Storage | $15.00 |
| 30 | 2 | Pay-roll of employés | Salaries, April, 1888 | 711.57 |
| May 7 | 3 | Charles H. Stuart | Pasturage | 96.00 |
| 30 | 4 | Pay-roll of employés | Salaries, May, 1888 | 705.20 |
| June 16 | 5 | Charles S. Cudlip | Photographic supplies | 13.20 |
| 23 | 6 | Park & Tilford | Field subsistence | 28.40 |
| 30 | 7 | Deerfoot Farm Company | ......do | 30.00 |
| 30 | 8 | Charles H. Stuart | Pasturage | 89.60 |
| 30 | 9 | S. W. Cook | Field material and labor | 158.60 |
| 30 | 10 | Pay-roll of employés | Salaries, June, 888 | 684.90 |
| | | | | 2,532.47 |

*Abstract of disbursements made by A. O. D. Taylor, jr., special disbursing agent, U. S. Geological Survey, during the second quarter of* 1888.

| | | | | |
|---|---|---|---|---|
| 1888. | | | | |
| Apr. 6 | 1 | Western Union Telegraph Company. | Telegrams | $2.85 |
| 2 | 2 | J. A. Williams | Services to April 1, 1888, inclusive | 94.10 |
| 25 | 3 | T. Nelson Dale | Traveling expenses | 4.20 |
| 30 | 4 | Raphael Pumpelly | Pay for April, 1888 | 329.70 |
| 30 | 5 | H. L. Smyth | ......do | 82.40 |
| 30 | 6 | A. O. D. Taylor, jr | ......do | 98.90 |
| 30 | 7 | T. Nelson Dale | ......do | 150.00 |
| 30 | 8 | A. Prescott Baker | Rent for April, 1888 | 50.00 |
| Mar. 4 | 9 | C. L. Whittle | Pay to March 3, 1888 | 99.04 |
| 31 | 10 | Henry Bull, jr | Telephone rent | 11.50 |
| May 8 | 11 | William J. Swinburne | Coal and wood | 175.20 |
| 8 | 12 | J. Elliot Wolff | Traveling expenses | 17.50 |

*Abstract of disbursements made by A. O. D. Taylor, jr., etc.*—Continued.

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1888. | | | | |
| May 1 | 13 | J. Elliot Wolff | Pay to April 30, 1888 | $98.90 |
| 9 | 14 | William Andrews | Cartage | 3.25 |
| 9 | 15 | Ben. K. Emerson | Pay to October 31, 1887 | 400.00 |
| 11 | 16 | Western Union Telegraph Company. | Telegrams, March and April, 1888 | 2.21 |
| 16 | 17 | Hayard & Horton | Repairing microscope case | 5.20 |
| 16 | 18 | Raphael Pumpelly | Incidental office expenses | 44.80 |
| 23 | 19 | Keuffel & Esser | Drawing materials | 22.17 |
| 23 | 20 | C. H. Codman & Co | Photographic supplies | 2.55 |
| 26 | 21 | Adams Express Company | Express charges | 8.75 |
| 26 | 22 | E. & H. T. Anthony & Co | Photographic supplies | 5.86 |
| 26 | 23 | J. Carbutt | do | 17.20 |
| 28 | 24 | T. Nelson Dale | Traveling expenses | 26.05 |
| 31 | 25 | Raphael Pumpelly | Pay for May, 1888 | 340.60 |
| 31 | 26 | H. L. Smyth | do | 85.20 |
| 31 | 27 | T. Nelson Dale | do | 150.00 |
| 31 | 28 | A. O. D. Taylor, jr | do | 102.20 |
| 31 | 29 | A. Prescott Baker | Rent for May, 1888 | 50.00 |
| 31 | 30 | Richard Bliss | Bibliographical work | 41.40 |
| June 1 | 31 | Algernon B. Corbin | Stationery supplies | 3.16 |
| 1 | 32 | Eimer & Amend | Chemicals | 34.94 |
| May 31 | 33 | Ben. K. Emerson | Pay for May, 1888 | 100.00 |
| June 8 | 34 | George W. Robbins | 1 eyelet punch and set | 8.00 |
| 8 | 35 | Western Union Telegraph Company. | Telegrams for May, 1888 | 3.89 |
| 9 | 36 | T. Nelson Dale | Traveling expenses | 20.25 |
| 12 | 37 | Alfred H. Brooks | do | 4.60 |
| 12 | 38 | H. L. Smyth | do | 9.55 |
| 12 | 39 | do | Field expenses | 9.50 |
| 12 | 40 | do | do | 12.33 |
| 12 | 41 | J. M. K. Southwick | Hardware supplies | 16.90 |
| 16 | 42 | T. Nelson Dale | Traveling expenses | 19.48 |
| 30 | 43 | H. L. Smyth | Pay for June, 1888 | 82.40 |
| 18 | 44 | J. Eliot Wolff | Pay to May 31, 1888 | 39.56 |
| 19 | 45 | H. L. Smyth | Field expenses | 9.00 |
| 21 | 46 | T. Nelson Dale | Traveling expenses | 13.00 |
| 22 | 47 | W. J. Withrow | do | 12.99 |
| 22 | 48 | H. A. Craigin | do | 9.64 |
| 22 | 49 | H. L. Smyth | Field expenses | 68.05 |
| 23 | 50 | R. D. Coggeshall | 11 hammer heads | 8.25 |
| 23 | 51 | Gustave Hamilton | 3 window shades | 3.93 |
| 25 | 52 | Phineas C. Clark | 11 hammer handles | 5.83 |
| 26 | 53 | Adams Express Company | Express charges | 20.40 |
| 27 | 54 | H. L. Smyth | Field expenses | 37.85 |
| 27 | 55 | do | do | 7.35 |
| 28 | 56 | do | Traveling expenses | 6.53 |
| 28 | 57 | Keuffel & Esser | Drawing materials | 9.73 |
| 28 | 58 | Edgar F. Clark | Services to June 28, 1888 | 150.00 |
| 30 | 59 | John Pumpelly | Rent of instruments | 65.00 |
| 30 | 60 | Caswell, Massey & Co | Chemicals, etc | 7.95 |
| 30 | 61 | A. Prescott Baker | Rent for June, 1888 | 50.00 |
| 30 | 62 | Raphael Pumpelly | Pay for June, 1888 | 329.70 |
| 30 | 63 | T. Nelson Dale | do | 150.00 |
| 30 | 64 | A. O. D. Taylor, jr | do | 98.90 |
| 30 | 65 | Ben. K. Emerson | do | 100.00 |
| 30 | 66 | Scovill Manufacturing Company | Photographic materials | 212.67 |
| 30 | 67 | Mrs. C. A. Wright | Services of Charles E. Wright, deceased. | 80.00 |
| 30 | 68 | Ben. K. Emerson | Field expenses | 9.50 |
| 30 | 69 | Pay-roll for June, 888 | | 130.55 |
| 30 | 70 | Henry Bull, jr | Telephone rent | 11.50 |
| 30 | 71 | Newport Water-Works | Water to June 30, 1888 | 9.00 |
| 30 | 72 | Charles E. Hammett, jr | Stationery supplies | 8.50 |
| 30 | 73 | W. & L. E. Gurley | Instruments, etc | 302.48 |
| 30 | 74 | Richard Bliss | Bibliographical work | 20.70 |
| 30 | 75 | G. P. Putnam's Sons | Stationery supplies | 41.14 |
| 30 | 76 | Frank H. Wilks | 1 chart case | 3.60 |
| 30 | 77 | Nathan Barker | Carpentry work | 25.73 |
| 30 | 78 | Raphael Pumpelly | Traveling expenses | 117.75 |
| 30 | 79 | do | Office expenses | 54.79 |
| 30 | 80 | T. Nelson Dale | Traveling expenses | 33.55 |
| 30 | 81 | A. O. D. Taylor, jr | do | 8.95 |
| 30 | 82 | H. L. Smyth | Field expenses | 23.88 |
| 30 | 83 | Edward Stabe | Traveling expenses | 9.45 |
| 30 | 84 | W. Beals, jr | do | 6.20 |
| 30 | 85 | Western Union Telegraph Company. | Telegrams, June, 1888 | 5.33 |
| | | | | 5,165.66 |

*Abstract of disbursements made by Fielding Barnes, disbursing agent, U. S. Geological Survey, during the second quarter of* 1888.

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1888. | | | | |
| Apr. 4 | 1 | Sumner H. Bodfish | Traveling expenses | $7.95 |
| 26 | 2 | R. M. Towson | Miscellaneous field expenses | 28.85 |
| 30 | 3 | Pay-roll of employés | Services, April, 1888 | 1,739.30 |
| 30 | 4 | W. R. Atkinson | Miscellaneous field expenses | 26.53 |
| June 30 | 5 | .....do | .....do | 28.30 |
| 30 | 6 | ......do | Traveling expenses | 10.25 |
| 30 | 7 | R. M. Towson | Miscellaneous field expenses | 45.35 |
| | | | | 1,886.53 |

*Abstract of disbursements made by R. R. Hawkins, special disbursing agent, U. S. Geological Survey, during the second quarter of* 1888.

| | | | | |
|---|---|---|---|---|
| 1888. | | | | |
| Apr. 2 | 1 | J. J. Vasconcellos | Field supplies, etc | $30.50 |
| 2 | 2 | H. L. Howse | Coal oil, etc | 6.90 |
| 2 | 3 | A. Carlisle & Co | Office and field supplies | 32.85 |
| 4 | 4 | M. Nolan | Labor | 10.00 |
| 12 | 5 | W. Lindgren | Field expenditures | 92.36 |
| 16 | 6 | A. Lietz & Co | Compass, etc | 11.26 |
| 16 | 7 | H. W. Turner | Traveling expenses | 45.25 |
| 23 | 8 | W. Lindgren | Field expenditures | 33.75 |
| 23 | 9 | Goldberg, Bowen & Co | Field supplies | 33.15 |
| 30 | 10 | E. A. Schneider | Services, April 1 to 30, 1888 | 60.00 |
| 30 | 11 | Pay-roll | ......do | 578.50 |
| 30 | 12 | G. W. Granniss | Rent of rooms | 52.66 |
| 30 | 13 | H. A. Messenger | Pasturing public animals | 37.50 |
| May 5 | 14 | H. W. Turner | Field expenditures | 52.98 |
| 9 | 15 | L. Jones | Labor, etc | 19.75 |
| 15 | 16 | W. Lindgren | Field expenditures | 59.90 |
| 18 | 17 | H. L. Howse | Supplies, repairs, etc | 20.00 |
| 18 | 18 | H. W. Turner | Field expenditures | 24.94 |
| 28 | 19 | W. Lindgren | ......do | 31.35 |
| 31 | 20 | G. W. Granniss | Rent of rooms | 52.66 |
| 31 | 21 | Pay-roll | Services, May, 1888 | 598.00 |
| 31 | 22 | John Taylor & Co | Laboratory supplies | 89.62 |
| 31 | 23 | E. A. Schneider | Services, May, 1888 | 60.00 |
| 31 | 24 | E. M. Sleator | Map | 10.00 |
| 31 | 25 | George Phillips | Services, May, 1888 | 45.00 |
| June 6 | 26 | W. Lindgren | Field expenditures | 31.05 |
| 8 | 27 | Frank Rader | Services, May, 1888 | 35.00 |
| 11 | 28 | Main & Winchester | Harness supplies | 23.75 |
| 14 | 29 | H. W. Turner | Field expenditures | 36.70 |
| 15 | 30 | ......do | Traveling expenses | 31.55 |
| 15 | 31 | Sam. C. Partridge | Photographic supplies | 16.95 |
| 19 | 32 | W. Lindgren | Traveling expenses | 11.15 |
| 21 | 33 | Goldberg, Bowen & Co | Field supplies | 11.38 |
| 23 | 34 | W. Lindgren | Field expenditures | 25.10 |
| 23 | 35 | L. Jones | Cartage | 9.75 |
| 25 | 36 | H. W. Turner | Field expenditures | 57.61 |
| 25 | 37 | Wells, Fargo & Co | Expressage | 20.75 |
| 27 | 38 | John Taylor & Co | Laboratory supplies | 65.45 |
| 27 | 39 | A. Carlisle & Co | Office and field supplies | 24.00 |
| 30 | 40 | Pay-roll | Services, June, 1888 | 578.50 |
| 30 | 41 | E. A. Schneider | ......do | 60.00 |
| 30 | 42 | N. V. Nelson | Pasturing public animals | 21.66 |
| 30 | 43 | George Phillips | Services, June, 1888 | 45.00 |
| 30 | 44 | Frank Rader | ......do | 35.00 |
| 30 | 45 | W. Lindgren | Field expenditures | 24.25 |
| 30 | 46 | A. Lietz & Co | Surveyor's rule, etc | 12.20 |
| 30 | 47 | G. W. Granniss | Rent of rooms | 52.66 |
| 30 | 48 | R. R. Hawkins | Sundry cash expenditures | 47.75 |
| | | | | 3,366.09 |

*Abstract of disbursements made by James C. Pilling, special disbursing agent, U. S. Geological Survey, during the second quarter of* 1888.

| | | | | |
|---|---|---|---|---|
| 1888. | | | | |
| May 21 | 1 | Eugene Ricksecker | Traveling expenses | $126.50 |
| 21 | 2 | ......do | Field expenses | 13.84 |
| 21 | 3 | George Engle | Subsistence | 11.77 |
| 21 | 4 | ......do | ......do | 19.85 |
| 21 | 5 | George H. Curry | Field supplies | 5.47 |
| 21 | 6 | ......do | ......do | 16.88 |

*Abstract of disbursements made by James C. Pilling, etc.*—Continued.

| Date of payment. | No. of voucher. | To whom paid. | For what paid. | Amount. |
|---|---|---|---|---|
| 1888. | | | | |
| May 21 | 7 | Pay-roll | Pay of employés | $215.71 |
| 21 | 8 | W. T. Griswold | Traveling expenses | 43.15 |
| 21 | 9 | ..... do | Field expenses | 33.96 |
| 21 | 10 | George H. Curry | Subsistence | 38.26 |
| 21 | 11 | G. W. Stephenson | Forage for public animals | 34.75 |
| 21 | 12 | S. F. Morine | Shoeing | 48.50 |
| 31 | 13 | Pay-roll | Pay-roll of employés | 232.92 |
| 21 | 14 | C. W. Howell | Services | 60.00 |
| June 6 | 15 | ......do | Field expenses | 46.75 |
| May 23 | 16 | R. H. McKee | Traveling expenses | 133.25 |
| 23 | 17 | H. M. Wilson | Field expenses | 74.50 |
| 23 | 18 | ......do | ......do | 53.40 |
| 23 | 19 | ......do | Traveling expenses | 53.70 |
| 23 | 20 | Western Union Telegraph Company. | Telegrams | 2.49 |
| 31 | 21 | Pay-roll | Pay of employés | 236.05 |
| 23 | 22 | E. T. Perkins, jr | Traveling expenses | 15.75 |
| 28 | 23 | R. H. McKee | Services, May, 1888 | 102.20 |
| 28 | 24 | Charles W. Howell | ......do | 60.00 |
| June 1 | 25 | E. C. Ryan | ......do | 60.00 |
| 2 | 26 | T. H. Cook & Co | Subsistence | 32.04 |
| 1 | 27 | Paul Holman | Traveling expenses | 57.95 |
| 1 | 28 | E. C. Ryan | ......do | 16.45 |
| May 31 | 29 | ......do | Field expenses | 19.50 |
| 31 | 30 | A. F. Dunnington | Traveling expenses | 130.50 |
| June 5 | 31 | W. B. Miller | Repairs | 4.00 |
| 5 | 32 | James C. Pilling | Traveling expenses | 170.75 |
| 4 | 33 | A. H. Thompson | Salary, May, 1888 | 230.00 |
| 5 | 34 | ......do | Traveling expenses | 107.44 |
| 14 | 35 | ......do | ......do | 179.05 |
| 30 | 36 | Charles W. Howell | Services, June, 1888 | 60.00 |
| 30 | 37 | A. T. Kyle, jr | Care and forage of public animals | 71.00 |
| 30 | 38 | ......do | ......do | 26.65 |
| 30 | 39 | James C. Pilling | Traveling expenses | 143.25 |
| | | | | 2,988.23 |

| | | |
|---|---|---|
| Total amount expended as per abstracts herewith during the fiscal year ending June 30, 1888 | | $484,238.57 |
| Amount of bonded railroad accounts settled through Treasury Department: | | |
| Freight | $526.70 | |
| Passenger | 1,286.87 | |
| | | 1,813.57 |
| Grand total | | 486,052.14 |

DEPARTMENT OF THE INTERIOR, UNITED STATES GEOLOGICAL SURVEY.

PAPERS ACCOMPANYING THE ANNUAL REPORT

OF THE

# DIRECTOR OF THE U. S. GEOLOGICAL SURVEY

FOR THE

FISCAL YEAR ENDING JUNE 30, 1888.

# THE CHARLESTON EARTHQUAKE

OF

AUGUST 31, 1886.

BY

CAPT. CLARENCE EDWARD DUTTON,

U. S. ORDNANCE CORPS.

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# THE CHARLESTON EARTHQUAKE OF AUGUST 31 1886.

By Capt. Clarence E. Dutton,
*U. S. Ordnance Corps.*

## PREFACE.

On the 31st of August, 1886, the day of the great Charleston earthquake, the writer of this monograph was at the Warm Spring Indian Reservation, in Oregon. Slowly crossing the Cascade Range, he reached Portland on the 10th of September, and there received the first intelligence of the catastrophe; nor did he reach Washington until about the 1st of October. Immediately after the earthquake the Director of the Geological Survey sent Mr. W J McGee to Charleston to examine its effects. Prof. T. C. Mendenhall, of the U. S. Signal Service, went a day later. Each of these gentlemen collected a large amount of valuable information, which was placed at my disposal. While in Charleston Mr. McGee became acquainted with Mr. Earle Sloan, and at once recognizing his ability, his interest in the subject, and his eminent fitness for scientific investigation, secured his services for the examination in detail of the effects of the earthquake in Charleston and in the epicentral tracts.

In the mean time Ensign Everett Hayden, of the Navy, who was on duty in my office, made diligent exertions to secure from all sources throughout the country information respecting the extent of the region over which it was felt, with indications of its intensity, the characteristics of the shocks or vibrations, the observed times of their advent, and their durations. A large number of circulars, containing the usual questions, were sent out, and it is gratifying to be able to say that most of them were answered. The substance of the circular was also published extensively in the newspapers, and its questions were voluntarily answered by many persons. Particular attention was paid by Mr. Hayden to the time reports, as it was hoped that data of exceptional value would be secured for the determination of the speed of transmission of the shocks. Much correspondence was entailed upon him in this research, and his investiga-

tions were conducted with great ability. I am also indebted to many correspondents throughout the country for valuable co-operation in the collection of data.

I must, however, mention with special gratitude the work of Mr. Earle Sloan, of Charleston, who undertook the investigation of the epicentral tract of the earthquake. With great labor and patience he studied the ground for two months, and subsequently reviewed portions of it, gathering together a large amount of information of the kind that was wanted, and submitting it in a form capable of being used intelligently. Without his researches some of the most valuable results of the study of this earthquake would never have been realized.

The epicentral tract is very scantily peopled, and artificial objects which could show the effects of the earthquake are comparatively few. The tract is mainly a forest region. The most notable structures which exist within it are the railroads, and within a few days all the effects of the earthquake upon them were necessarily obliterated. With the utmost diligence Mr. Sloan collated every attainable fact of this evanescent character before it was effaced, or at least before it was forgotten. Certainly the most valuable characteristic of Mr. Sloan's work is the candid, impartial spirit with which every observation was made and the just weight which is attached to every fact. It is impossible to bestow higher praise upon an observer.

In the preparation of this work it seemed necessary that an account of the scenes in Charleston during and immediately following the catastrophe should be embodied, and that it should be written by some one who was present in the city at the time. After consultation with several gentlemen who reside there it was decided that Dr. G. E. Manigault, of the Charleston College, should be invited to perform this task. His scientific knowledge, his calm, judicial temperament and his familiarity with the facts were well known, and a better selection could not have been made. Meanwhile Mr. Carl McKinley, assistant editor of the Charleston News and Courier, had been requested by the city authorities to prepare an account for publication in the Charleston Year Book, the annual report of the city government. This very graphic and eloquent, yet withal faithful and judicious, narrative is so excellent a description, that it seemed worthy of reproduction in the present monograph. Mr. McKinley cordially assented to my request for permission to embody it as a separate chapter.

When this work was begun it was hoped that, with the large amount of data which seemed attainable, results of exceptional value and instructiveness would be reached. In the course of a few months nearly four thousand reports, from about sixteen hundred localities, were obtained, all of which were card-catalogued as fast as they were received. The hopes have been only partially realized.

One result of importance has indeed been attained. We now know within a close approximation how fast an earthquake wave is propagated, and after a careful study of all discussions of this particular problem, based upon the observations made in other earthquakes, I have no hesitation in declaring my opinion that the result from the Charleston earthquake far outweighs them all, and that all preceding determinations of this quantity are wholly invalid and wide of the mark.

The most striking feature of the present result is its coincidence with the rate of propagation, which is indicated by the theory of wave motion as the proper one for an elastic, nearly homogeneous, solid medium, composed of such materials as we know to constitute the rocks of the outer portions of the earth. Thus a new fact may be said to be added to the sum of human knowledge. But after the most careful and prolonged study of the data at hand, nothing has been disclosed which seems to bring us any nearer to the precise nature of the forces which generated the disturbance. Severe labor has been expended for many months in the endeavor to extract from them some indications respecting this question, but in vain. This problem remains where it was before. Having nothing to contribute towards its solution, I have carefully refrained from all discussion of speculations regarding the causes of earthquakes.

C. E. DUTTON,
*Captain of Ordnance, U. S. Army.*

# CHAPTER I.

## THE EARTHQUAKE AT CHARLESTON.

By Carl McKinley.

[Note.—The following description was first published in part in the Charleston News and Courier of September 3, 1886. At the invitation of the city authorities its writer, Mr. Carl McKinley, of the editorial staff of that paper, undertook the preparation of an account of the earthquake for publication in the Charleston Year Book. This description, which had the advantage of being prepared in the first instance within a few hours after the disaster by one who had the best possible facilities for obtaining information, was subjected to only a few verbal changes, but was greatly amplified and supplemented in the light of information afterwards obtained. The whole constitutes a large, valuable, and very interesting contribution to the history of that momentous event. Mr. McKinley has, with great courtesy, permitted me to make any use of his paper that may be of service in connection with the present work. For the present I select this description, reserving the other parts of his paper for use in those places where they will adapt themselves to the plan and logical order of this work and fall into relation with other matters of similar character.—C. E. D.]

While engaged in his usual duties on the second floor of The News and Courier building (Fig. 1) at the time of the first shock, the writer's attention was vaguely attracted by a sound that seemed to come from the office below, and was supposed for a moment to be caused by the rapid rolling of a heavy body, as an iron safe or a heavily laden truck, over the floor. Accompanying the sound there was a perceptible tremor of the building, not more marked, however, than would be caused by the passage of a car or dray along the street. For perhaps two or three seconds the occurrence excited no surprise or comment. Then by swift degrees, or all at once—it is difficult to say which—the sound deepened in volume, the tremor became more decided, the ear caught the rattle of window-sashes, gas-fixtures, and other movable objects; the men in the office, with perhaps a simultaneous flash of recollection of the disturbance of the Friday before at Summerville, glanced hurriedly at each other and sprang to their feet with the startled question and answer, "What is that?" "An earthquake!" And then all was bewilderment and confusion.

The long roll deepened and spread into an awful roar, that seemed to pervade at once the troubled earth and the still air above and around. The tremor was now a rude, rapid quiver, that agitated the whole lofty, strong-walled building as though it were being shaken—shaken by the hand of an immeasurable power, with intent to tear its joints asunder and scatter its stones and bricks abroad, as a tree casts its over-ripened fruit before the breath of the gale.

There was no intermission in the vibration of the mighty subterranean engine. From the first to the last it was a continuous jar, adding force with every moment, and, as it approached and reached the climax of its manifestation, it seemed for a few terrible seconds that no work of human hands could possibly survive the shocks. The floors were heaving underfoot, the surrounding walls and partitions visibly swayed to and fro, the crash of falling masses of stone and brick and mortar was heard overhead and without, the terrible roar filled the ears and seemed to fill the mind and heart, dazing perception, arresting thought, and for a few panting breaths, or while you held your breath in dreadful anticipation of immediate and cruel death, you felt that life was already past and waited for the end, as the victim with his head on the block awaits the fall of the uplifted ax.

For a second or two it seemed that the worst had passed, and that the violent motion was subsiding. It increased again and became as severe as before. None expected to escape. A sudden rush was simultaneously made to endeavor to attain the open air and fly to a place of safety; but, before the door was reached all stopped short, as by a common impulse, feeling that hope was vain—that it was only a question of death within the building or without, of being buried beneath the sinking roof or crushed by the falling walls. The uproar slowly died away in seeming distance. The earth was still, and oh! the blessed relief of that stillness!

But how rudely the silence was broken! As we dashed down the stairway and out into the street, from every quarter arose the shrieks, the cries of pain and fear, the prayers and wailings of terrified women and children, commingled with the hoarse shouts of excited men. The air was everywhere filled to the height of the houses with a whitish cloud of dry, stifling dust, arising from the lime and mortar of the shattered masonry, which, falling upon the pavement and stone roadway, had been reduced to powder. Through this cloud, dense as a fog, the gas-jets flickered feebly, shedding but little light, so that one stumbled at every step over the piles of bricks, or became entangled in the telegraph wires that depended in every direction from their broken supports. On every side were hurrying forms of men and women, bareheaded, partially dressed, some almost nude, and all nearly crazed with fear and excitement. Here, a wife is supported, pale and fainting, in the arms of her husband. Her arms hang listlessly by her side, her head has fallen backward on his shoulder; he bears her past, whispering words of encouragement in answer to her low and repeated moans, and they are lost in the mist. A few steps away, under the gas-lamp, a woman lies prone and motionless on the pavement, with upturned face and outstretched limbs, and the crowd which has now gathered in the street passes her by, none pausing to see whether she is alive or dead. A man

in his shirt sleeves, with blood streaming over his clothing from a wound on his head, moves about among the throng without being questioned or greeted; no one knows which way to turn, or where to offer aid; many voices are speaking at once, but few heed what is said; you take note of all these things as one in a dream. The reality seems strangely unreal; and through it all is felt instinctively the presence of continuing, imminent danger, which will not allow you to collect your thoughts or do aught but turn from one new object to another.

A sudden light flares through a window overlooking the street. It becomes momentarily brighter, and a cry of "Fire!" resounds from the multitude. A rush is made towards the spot; a man is seen lying doubled up, silent and helpless, against the wall; but at this moment, somewhere—out at sea—overhead—deep in the ground—is heard again the low ominous roll which is already too well known to be mistaken. It grows louder and nearer, like the growl of a wild beast swiftly approaching its prey, and all is forgotten in the frenzied rush for the open space, where alone there is hope of security, faint though it be. The tall buildings on either hand blot out the skies and the stars, and seem to overhang every foot of the ground between them. Shattered cornices and copings, the tops of the frowning walls, lie piled from both sides to the center of the street. It seems that a touch now would send the broken masses left standing down upon the people below, who look up to them and shrink together as the tremor of the earthquake passes under them, and the mysterious reverberations swell and roll along like some infernal drum-beat summoning them to die. It passes away, and once more is experienced the blessed feeling of deliverance from impending calamity, which, it may well be believed, evokes a mute but earnest offering of mingled prayer and thanksgiving from every heart in the throng.

Again, far along the street, and up from the alleys that lead into it on either side, is heard the chorus of wails and shrieks, shouts and prayers, which, though it had not ceased, was scarcely noticed a moment before. It is a dreadful sound; the sound of helpless, terror-stricken humanity, old and young, the strong and the feeble alike where all are so feeble, calling for help from their fellow-creatures, and raising their voices in anguished petition to Heaven for mercy, when no human aid could avail.

It is not a scene to be described by any mortal tongue or pen. It is not a scene to be forgotten, when once it has been witnessed, and when the witness has shared all its danger and felt all its agony.

The first shock occurred at about 9.51 o'clock, as indicated by the public clocks, the hands on all of which stopped at that fateful point, as if to mark the end of time for so many who had counted the recording strokes of the preceding hour without a thought but

of long and happy life. The second shock, which was but a faint and brief echo of the first, occurred eight minutes later.

Soon after it had passed the writer started homeward, to find the scenes enacted on Broad street around The News and Courier office repeated at every step. (Fig. 1.) St. Michael's steeple towered high and white through the gloom, seemingly uninjured. (Pl. X.) The station-house, a massive brick building across the street, had lost its parapet and the roof of the portico, which had fallen in a mass—killing a woman, whose body then lay under the wreck. A little farther on the portico of Hibernian Hall (Pl. XI), a handsome building in the Grecian style, had crashed to the ground, carrying down the massive pillars with it. All the way up Meeting street, which, in respect


Fig. 1. View on Broad street.

of its general direction and relative importance, corresponds with Broadway in New York, the ground was piled with débris from the tops of the walls on either side. In passing the Charleston Hotel, which, to carry out the comparison above indicated, occupies the position of Stewart's uptown store in New York, the third shock was felt about ten minutes after the second, and of course caused the greatest alarm in that neighborhood, as elsewhere. At Marion

Square, corresponding with Union Square, New York, a great crowd had already collected, as even the borders of the extensive plaza could not be reached by the nearest buildings in event of their fall, and the number of fugitives was momentarily increased by new arrivals pouring in from every side. (Pl. VII.)

From this crowd, composed of men, women and children of both races, arose incessant calls and cries and lamentations, while over the motley, half-clad assembly was shed the lurid light of the conflagration that had broken out a hundred yards beyond the square immediately after the first shock, and now enveloped several buildings in flames. In three other quarters of the town, at the same time, similar large fires were observed under full headway;[1] and the awful significance of the earthquake may be most fully appreciated, perhaps, when it is said that, with these fires blazing up at once around them, the people whom you met on the streets, or saw gathered together in groups in the open places, evidently did not give them a thought. No one watched the ruddy flames or the black pillars of cloud rising high into the still night air. All were too intent on listening for the dreaded recurrence of that horrible growl or groan of the power under the sea and under the land, or on watching for the next manifestation of the mysterious force, to give a thought to the more familiar terror, though it had threatened his own home and every house in the doomed city.

Arrived at his home, the writer found the same condition of affairs that prevailed elsewhere. Every house in the vicinity was deserted. Interrupted in their evening pursuits, or aroused from sleep by the shocks and the sound of the fearful ruin being effected above and around them, the alarmed inmates had rushed into the streets, and were huddled together, trembling and fearful, awaiting the end, whatever it might be. Invalids had been brought out on mattresses and deposited in the roadway, and, together with the aged and the infant, were cared for as tenderly as possible. No thought was given anywhere to treasures left behind in the effort to save the priceless treasure of life itself—suddenly become so precious in the eyes of all who were threatened to be bereft of it.

The presence of the dead and wounded who were conveyed to the parks and public squares, added greatly, of course, to the distress of the already dismayed refugees in those places. The bodies of the victims were laid on the ground in the midst of the camps, the dead being covered from sight by shawls or sheets, while skilled hands ministered to the sufferers who were yet within the reach of human aid. The physicians and surgeons performed their duty throughout the night with heroic devotion, and many chapters would be required to tell the story of their labors alone as it should be told.

Exaggerated rumors as to the number of the killed spread through-

[1] Nearly twenty buildings were burned, and all were on fire at the same time.

PUBLIC SQUARE IN CHARLESTON AFTER THE EARTHQUAKE.

out the city soon after the shock, causing needless pain to many who, though spared the sight of the scenes of suffering and death so near to them, yet feared for the safety of relatives and friends of whom no tidings could be heard.

The long, anxious watch between midnight and day was not less trying than the shock itself. The suspense was indescribably painful, and had no relief for a moment, save when it gave place to recognition of the approach and presence of renewed danger. That passed, the breathless vigil began again, and the moments seemed as hours and the hours as moments until the next dread visitor had come and gone. Four severe shocks occurred before midnight. Three others followed at about 2, 4, and 8.30 o'clock, a. m., and every shock after the first caused even more alarm, naturally, than the first itself.

The apprehension of further and perhaps greater ill was shared by every one, and was not relieved for an instant. The character and extent of the disturbing force were not known, nor was there any reason to believe that the hardest shock had been experienced. Whether the blow had come from the sea or from the land none could say. At any moment another might be felt that would rend the earth asunder, or burst the bounds that held the waiting ocean in check and drive its waters sweeping in an overwhelming wave over all the low-lying peninsula where so many thousands were collected together without hope of escape. Night and distance shut out all the world. No word could be heard from beyond the confines of the stricken city; no human hand could be stretched to save a single soul, whatever fate was impending. The silence, save when broken by piteous cries, was oppressive in the extreme. In the late hours of the night even such cries would have been a relief to senses that were strained to so great tension to catch the first footstep of coming danger, the first low moan of the earth in the throes of convulsion. The air itself was strangely still. In the writer's garden an unprotected lamp burned until 4 o'clock, or later, with a flame that did not once waver. All nature seemed to be waiting in breathless suspense for the issue of the hour, of the next minute, the next moment. And then! always with startling suddenness, the great fearful Power rushed out of the darkness upon the city, shaking the ground with his tread, sending terror before him, and leaving trembling thousands panting in dismay as he passed. The impressions received at the time have doubtless become obscured by familiarity with the danger, and by the sense of comparative security that has since prevailed. The record of the night, none the less, is engraved too deeply in many hearts ever to be erased, and these will bear witness yet that this faint sketch enlarges no detail of the trials they endured that night for hours that seemed whole nights in themselves.

The rising sun on Wednesday morning looked on empty and broken homes and on streets encumbered with continuous lines or heaped masses of ruins, amidst which the wearied and shelterless citizens gathered together in little groups, or picked their way from place to place, wondering at the extent of the damage inflicted everywhere, and with renewed thankfulness in view of the perils escaped. No one was prepared for the scene that was presented by daylight. Every house was in worse condition than had been suspected. Some were utter wrecks, and many others were but little better off. For the first time the magnitude of the disaster began to be somewhat appreciated.

Those who flattered themselves that the morning had brought an end to their terrors and trials, however, and who timidly ventured to return within doors to commence the work of temporary repair or to provide for the wants of the day, were quickly undeceived. Another shock occurred about 8.30 o'clock, and caused the more excitement and apprehension because of the knowledge, that had now become general, of the dangerous condition of the buildings, and of the effects that might be expected to follow any further violent agitation. It had become known, too, that very many persons had been killed and wounded during the night,[1] and that the ground had opened in numerous places in and around the city, the number and extent of the fissures being of course greatly exaggerated. Some alleged authoritative predictions of further violent shocks had also obtained circulation and credence. The latest shock, therefore, naturally caused wide-spread consternation. Another occurred about 1 p. m., another at 5 p. m., and another about 8 p. m. Those of the day fully determined all to avoid their houses until the disturbances had ended or appreciably moderated. Tents, awnings, and rude habitations of varied description were erected everywhere for such protection as they could afford. The entire population of the city was collected in the parks and streets, except a few families that had found refuge on the ships in the harbor. There was no lack of food, except that caused by the limited means for preparing it. The day was spent in improvising such necessary arrangements for camping out as the circumstances required and permitted.

The general aspect of the city is scarcely a subject for detailed description, and can more readily be conceived than put in words. It is enough to say that not more than a half dozen houses escaped injury, and that the damage to all would be represented by the demolition of one-fourth of the buildings on Charleston Neck; by the leveling of the houses south of Broad street; or by the destruction

[1] The number of killed, as shown by the official records, was 27: whites, 7; colored, 20. The number of wounded has never been ascertained. The total number of deaths attributed to injuries, cold, and exposure was 83, which is not believed to cover the actual deaths from these causes.

of a city larger than Columbia. The ruins lay piled in the streets, yards, and gardens, and the houses from which they had fallen seemed ready to crumble of their own weight. Travel was confined to the middle of the streets and was impeded there. It is impossible to estimate, even approximately, the amount of masonry that was thrown into the streets; but it may be guessed at in some sort when it is said that the wreckage caused by the cyclone of the year before amounted to over ten thousand cart-loads, all of which was removed within the week following. The débris in a few streets after the earthquake would have equaled in mass all of a similar kind that was caused by the storm, and every street was obstructed more or less throughout its length.[1] The work of removal was continued for months, and at the end of the year, and after, unsightly piles were still encountered in out of the way places, where they did not interfere with public or private convenience. There was enough, and more than enough, evidence of the ruin that had been wrought to oppress the most hopeful mind, and strangers visiting the city during the succeeding winter season were appalled by even the remaining signs of destruction which met their view. What it all meant to the people of Charleston on the morning of September 1, and the emotions to which it gave rise, can not be told. But the people were familiar with disaster, and one or two days later the writer saw a crowd of common laborers busily engaged in picking out and piling bricks from the wreck of the fallen wall of a building while the standing walls beside them were being shaken almost hourly by the recurring tremors.

Communication with the outer world was cut off simultaneously with the first shock, the railways having been rendered impassable

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[1] The damage caused by the cyclone was finally estimated at about $1,500,000. The records of the city assessor's office show that the damages caused by the earthquake were officially estimated during the following week at about $5,000,000. The United States Engineer Commission, appointed at the request of the mayor to determine the condition of the houses, carefully examined nearly two thousand buildings. In their report they say: "We estimate approximately that the buildings upon which we have rendered reports can not be thoroughly repaired for less than $2,000,000, and the remaining buildings, while of slight consequence as regards their danger to their owners, their occupants, and the public, will swell the moneyed value of real estate damages to a total of from $5,000,000 to $6,000,000." A board of inspectors, consisting of an architect and builder, were also appointed by the insurance companies transacting business in Charleston to investigate the condition of the houses. The board reported that they had inspected 6,956 buildings; that 90 per cent. of the brick buildings were injured more or less, while frame buildings suffered from falling chimneys, cracked plastering, and injured foundations; that "not 100 out of 14,000 chimneys escaped injury, and 95 per cent. of these 14,000 were broken off at the roof and went to the ground." The whole number of buildings adjudged unsafe and ordered to be pulled down was 102. Some of these were preserved by wholesale repairs, while others, that were not condemned by the commission, proved to be wrecks on closer examination, and were demolished by the owners.

to trains, and the telegraph lines broken down in the city and for a long distance without. Nothing was known on Wednesday of the area of the disturbance, nor whether Charleston had suffered more or less than other places. The isolation was, of course, a source of additional anxiety, and the inhabitants of the city were shut up to the contemplation of their own trouble and danger. Later in the day a brief telegraphic dispatch was sent abroad, and afforded the first information to the country that the coast had not been swept and submerged by a tidal wave, as was reported and believed. Fuller accounts were sent to Summerville by The News and Courier, and were thence telegraphed, via Washington, to the press of the United States for publication next day. The first detailed information received in Columbia, Augusta, and other neighboring cities as to the condition of affairs in Charleston was obtained in this way on Thursday morning. Reports from without were also received in Charleston by this time, and showed that the greatest force of the shock had been expended in and around the city. The volcanic theory, which had been promptly advanced by some to account for the shocks, obtained prominence on the strength of the information, and was re-enforced by rumors that steam and smoke and blue flames had been seen issuing from fissures near Summerville and elsewhere and that showers of pebbles had fallen in places in the city. The steam and smoke and flames had their origin in excited imaginations. Two slight "showers" of pebbles, to the amount of perhaps a quart or more, undoubtedly fell in the rear of The News and Courier building. The phenomenon was confined, so far as known, to a space of fifty square yards, and its source must be inferred from these facts.

For several days after the railroads were first repaired, which was promptly effected, every train was crowded with panic-stricken refugees fleeing to the upper portions of the State, where they were kindly welcomed and hospitably cared for. It was a time of general alarm and fear of immediate further disaster. The railroads generously offered free transportation to those who could not pay their way, and the number of fugitives ran up into the thousands before a feeling of comparative confidence and safety was restored.

It must not be supposed, however, that all the citizens were so demoralized. The authorities and subordinates in every department of the local government remained at their posts and discharged their difficult and added duties with a zeal and ability befitting the occasion, and that took no note of personal risk or private interest. Aid and relief were promptly extended to all who were in need. The public offices and institutions were kept open or removed to convenient places; order was preserved; private citizens devoted their time, energies, and money without stint to the service of the community; and so efficiently was the work of organized succor per-

formed, both then and later, that none, however poor and humble, who made his wants known or could be discovered by vigilant inquiry and search, suffered for food or for such shelter as could be provided. The pastors of the various congregations labored steadfastly and untiringly in their peculiar sphere and in assisting the efforts of the relief committees. The ladies of the city forgot their own fears and discomforts in ministering to the necessities of the wounded, the suffering, the sick, and the poor. Thousands of blacks and whites alike—no difference was recognized and no discrimination shown—were the recipients of the bounty of their more fortunate fellow-citizens, who proved to be neighbors indeed in the hour of misfortune. There were, too, it need scarcely be said, countless instances of unselfish devotion, of kind and loving regard, between master and servant, mistress and maid, throughout the whole season of trial, that showed, as could not have been shown under any other circumstances, how strong is the tie that yet binds the races together.

This experience of the dread occurrence will never be forgotten on either side. An additional evidence of the helpful and generous spirit that actuated all classes was afforded by the conduct of the captains and crews of the vessels in port. These vessels, of every size, were quickly crowded by families that fled to them for refuge, and all who came were made welcome and were provided for to the limit of the ability of the sea-faring men in so unlooked-for an emergency. Common sailors, some of whom had been made familiar with like scenes by their experience in the ports of other countries, went ashore early on Wednesday morning and labored hard, without offer or thought of compensation, in every place where their services could be employed. The names of these gallant and humane toilers of the sea can not be recorded, but their deeds are known, and their noble conduct will ever be remembered to the honor and glory of their calling.

The rare devotion to duty displayed by the firemen, the hospital nurses, and others, on Tuesday night, as well as the arduous and admirable labors of the several relief committees in response to the exacting demands made upon them during the long weeks of trial that followed, deserve the fullest recognition. The public records show in how high appreciation the conduct of all these is held, and will always be held, by the community. It is not necessary to attempt to add aught here to what has been said so well by the representatives of the people themselves. The story of the receipt and distribution of the offerings of half the world to the stricken city would alone fill a volume. It can not be told in these pages, and the grateful task must be left to those to whom it has been committed.

The spirit of the business community was likewise displayed in the most favorable light. Many of the merchants and managers of the various industries in the city were prominently identified with the work of relief or the control of affairs by virtue of their position, or influence, or peculiar fitness for the duties suddenly imposed upon them; but aside from these numerous individual instances, the business men as a body showed rare courage and energy in the presence of so adverse conditions. Some of the stores were closed during Wednesday, and some had been destroyed or rendered unsafe for occupation. By noon of Thursday, however, all were open for business that could be opened, and the novel wants of the public were promptly supplied. Some of the stores, indeed, presented an appearance of unusual activity, and systematic inquiries conducted by the reporters of The News and Courier elicited the brave responses that "business was as good as could be expected under the circumstances;" that "Charleston had pulled through great disasters before, and would survive the latest and greatest one;" that all were "ready to meet every demand that could be made upon them;" that "goods would be shipped to the country to fill orders by the first outgoing train and every succeeding one;" that "a good fall trade was expected, earthquake or no earthquake;" and that "Charleston was a good enough place for them, and they intended to stick by it as long as their buildings and the ground held together." These were not empty words nor idle promises. All that was said was meant, and every promise was kept to the letter. Twenty-four hours later the tide of business had nearly resumed its usual flow, and no dealer or buyer outside of the city had reason to complain that the effects of the shock had been felt in any of the multitudinous channels of trade and enterprise. A better showing than this surely was never made by business men anywhere under circumstances of great public depression or calamity.

Wednesday night was passed out of doors by practically the entire population of the city. Tents were constructed of carpets, blankets, shawls, sheets, etc., and they who could sleep rested on pallets spread on the ground, or on couches formed of the material at hand. The children of one of the orphan houses were sheltered by planks placed at an angle against the fence surrounding their play-ground, under which cover the little ones lay down together. Prayer meetings were held in many places, and the singing of hymns and the exhortations of the colored pastors addressing their flocks were heard on every hand.

A few minutes before midnight a sharp tremor occurred, which startled the watchers and brought many sleepers to their feet. The singing and exhorting, which had somewhat subsided, broke out anew and continued until a late hour. It is recorded of this tremor that its coming was preceded by quite a number of explosions, re-

mote and subdued in sound, which began to be heard fully five minutes before the vibration was felt; and that "its passage was marked by the sound of falling walls and buildings." The words which are quoted contain an erroneous idea of the force of the disturbance. The sound referred to was probably caused by the falling of masonry that had been badly shattered by the first shock and was readily overthrown. The tremor was not much more severe, perhaps, than those of the day, but, occurring in the night, and so near the time of the heavy shock on the night before, it sufficed to drive sleep from many eyelids until day dawned again. It will scarcely excite either surprise or amusement when the fact is mentioned that the sudden peal of an alarm clock in one of the camps in the morning hours emptied every tent within hearing.

The fears of the people gradually moderated during the week following, notwithstanding decided tremors continued to be felt at intervals. A few returned to their houses; those who remained in the camps made themselves as comfortable as they could. Food was systematically distributed by the relief committees to all who applied for it, and substantial huts and shanties were speedily erected in the public squares and vacant lots, adding greatly to the comfort of the refugees, and providing retreats in case of rain. Tents were sent into the city from every part of the country, as soon as the need of them was generally known. The supply eventually exceeded the demand. The weather remained dry and fine during the period when the people were most exposed and sometime afterwards, except for a heavy shower on Sunday night, September 5, that wet many of the campers-out to the skin and made their condition miserable indeed.

The experience of the people on the islands and the mainland immediately around Charleston must be gathered from the reports published at the time; and in the absence of any means of verifying the accounts given, the statements as to some of the effects of the shock must be received with allowance for the excited condition of the observers.

At Mount Pleasant, and at Moultrieville on Sullivan's Island, the shocks and tremors were felt about the same time as in Charleston, but were somewhat subdued in force. The description of events and scenes in the city may therefore be applied to these two villages in some measure, the difference in their favor being that no loss of life or personal injury befell any of their inhabitants, owing, doubtless, to the fact that frame residences are the rule in both places. No great damage was inflicted upon the houses, which, however, were rudely rocked about, causing the overthrow of most of the chimneys and a general breaking of plastering, crockery, and glassware. The shocks on Tuesday night of course caused great excitement and terror, and the people spent the night in the open

air, and shared to the full the fearful anticipations of their neighbors and friends in the city. Rumblings were plainly heard before every shock. There were no falling buildings at either place to produce these sounds, and it may be accepted, therefore, that the roarings heard in Charleston were not so produced.

A number of young people were assembled at a dancing party on the island, and all heard the premonitory roar too plainly to be mistaken. The statement of the reporter of The News and Courier, who was present, is as follows: "Not more than three dances had taken place, when above the strains of the band came the now familiar and much-dreaded, low, rumbling noise. Every one stopped instantaneously to listen. Ten seconds afterwards the house rocked so violently, that for the moment it was doubtful if it would stand." The same writer noticed that the initial disturbance was made up of three successive shocks, following each other so closely, that one scarcely ended before another began. This fact was observed by other persons in Charleston and elsewhere.

Many small fissures in the ground were found next morning in and near the village of Mount Pleasant, being of the same character as those in Charleston, though much more numerous. The depths of the fissures could not be determined, and the surface of the ground about them was covered with quantities of ejected mud and water. One of the public wells in the village, about twenty feet in depth, had filled with soft mud, that was forced upward with so great energy as to throw off the covering of the well and overflow the street for some distance. On the beach were small mounds of "sand," in which were depressions containing fresh water. A large basin or sink in the village, which was dry on Tuesday, was likewise discovered to be filled with fresh water. Immediately after the great shock on Tuesday night a strong odor, remarkable for the presence of sulphur gases, permeated the atmosphere, and was perceptible throughout the night. The same odor was detected in Charleston, but was there lost in others of a more offensive character.

On James Island "the rumbling was distinctly heard before any shock was felt," and the direction of the motion was reported to have been "from the southwest, passing off towards the north." The island was violently shaken, "many persons being unable to leave their beds until the first shock was over." In hundreds of places the earth opened in long cracks, from many of which large bodies of cold water, mixed with sand and blue mud, gushed out. These cracks appeared principally in low places. The population of the island passed the night out of doors. The colored people organized religious meetings, and the time until daylight was passed in singing and praying in the churches. The sensation of nausea, that was felt so generally by people in Charleston, was also felt by people on the island.

The correspondent who made the foregoing report of the disturbance was in a boat, about a quarter of a mile from shore, when the disturbance occurred. The effect of the shock, under these circumstances, is thus described: "The boat was drifting, and the rumbling noise could be heard distinctly, coming from the sea, before any shock was felt. Then the keel of the boat seemed seized by a mighty hand and violently shaken from side to side, producing a feeling closely approaching sea sickness in all the occupants." It should be noted that the correspondent, who was most favorably situated for the purpose of observation, testifies that the roar was heard distinctly before the shock was felt; and that the sensation experienced by the occupants of the boat was unmistakably that of nausea. The nervous excitement and nausea experienced by so many persons in Charleston and elsewhere are commonly attributed to an electric agency, but appear from this statement to have been the effects of the violent and unaccustomed motions to which they were subjected.

In St. Andrew's Parish, which lies across the Ashley River from Charleston, numerous small holes and craterlets were formed by the shock, and from these blue mud and parti-colored sands were emitted in varying quantities, the water and mud spouting up in places during a short interval to the height of five or ten feet. (Pl. XXIII.)

At Cainhoy, a small settlement near the headwaters of Cooper River, twenty shocks were reported to have been felt on Tuesday night; no greater damage being occasioned, however, than the destruction of chimneys. The water of the river, which at that point is half a mile wide, was "violently disturbed during the first three shocks," and great quantities of mud and water were ejected from a large fissure near the village. A wave of considerable height was reported by the colored people to have advanced up Cooper River at the time of the first shock, and to have overflowed the neighboring rice fields. The fact of the overflow was subsequently established, but its origin has not been clearly determined. The undulating motion of the ground at Cainhoy was reported to have been so violent that it was very difficult for a person to stand erect while it continued. A sensation of oppressive heat is said to have preceded the shock at that place, and it is distinctly noted that a sudden deep rumbling sound was heard before any tremor was felt.

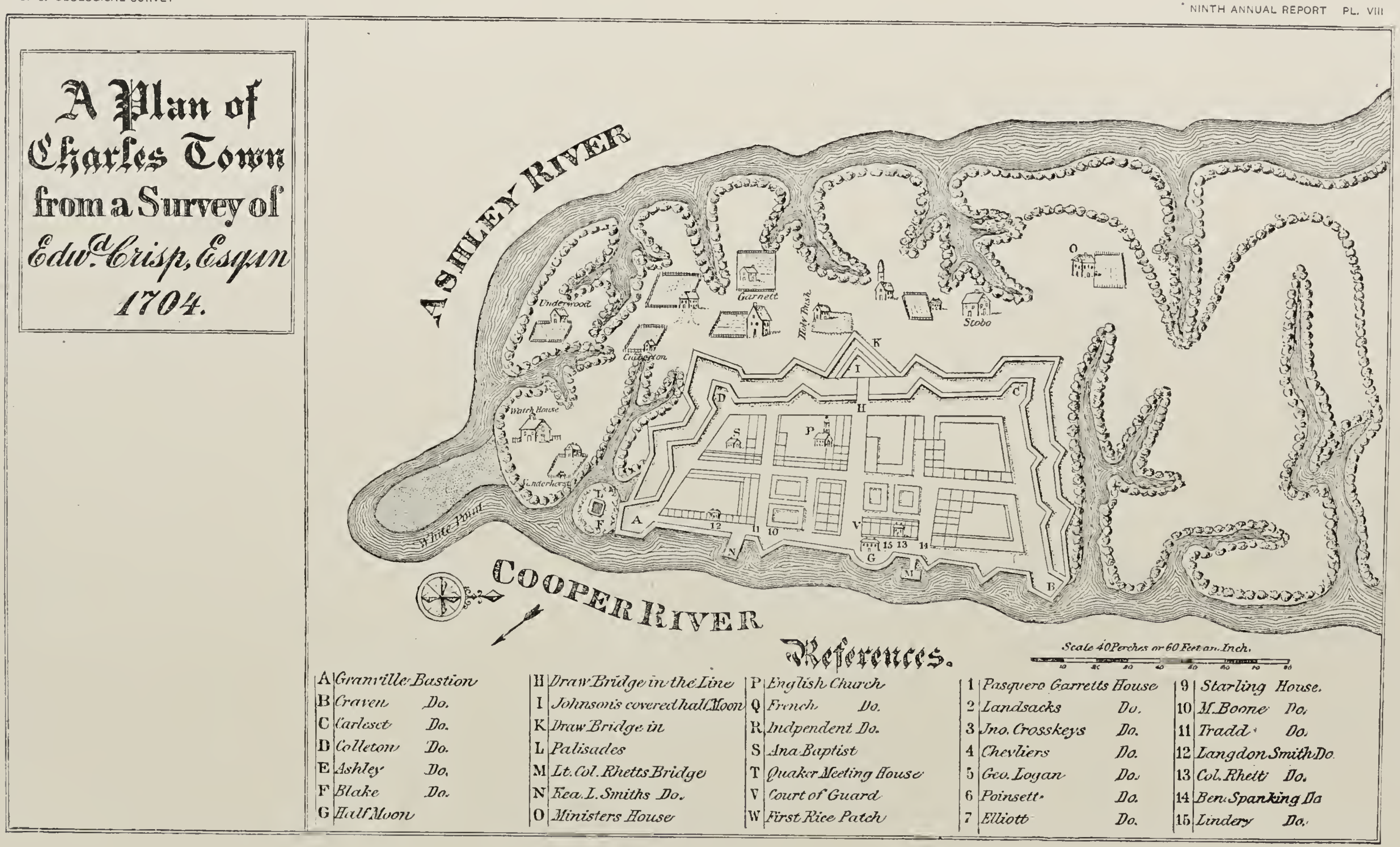
These reports, and others that might be added, show that the shock was felt in the country, for miles in all directions, nearly as strongly as in Charleston; that the same alarm prevailed everywhere; that the testimony as to the duration and direction of the agitation is hopelessly conflicting; and that the roar was certainly heard before the shock was felt in nearly every instance.

## THE EARTHQUAKE AT CHARLESTON.

By G. E. Manigault, M. D.

The city of Charleston, S. C., as the accompanying map, Pl. IX, will show, is situated on a narrow tongue of land between the two rivers Ashley and Cooper. In order the better to understand the nature of the site another plat of the locality at the time of the founding of the city is added (Pl. VIII). This will enable any one to comprehend how, owing to the numerous creeks with which this tongue of land was intersected, it became necessary, as the city extended its limits, to fill up those low places; and whenever to this day any building is being erected on "made land" if the owner desires a solid and permanent construction, it is absolutely necessary for him to undergo the expense of piling thoroughly for his foundations.

Fig. 2. Residence of ante-Revolutionary period.




MAP OF CHARLESTON IN 1704.

The first important public buildings erected under the colonial government were located upon the most elevated sites that could be found at the south end of the promonotory. The churches of St. Philip and St. Michael, the Exchange (Fig. 3), now the post-office, and the powder magazine in Cumberland street, between Church and Meeting streets, are evidences of this choice. The ground on which they stand is solid ground, and, as specimens of substantial brick-work, the three last named cannot be excelled by any building that dates from the same period in any of the older Atlantic cities. St. Philip's Church is excepted from this favorable opinion as to substantial construction, because the original building was destroyed by fire in 1835, and the rebuilding of the church dates from that year. (Pl. XVI.)

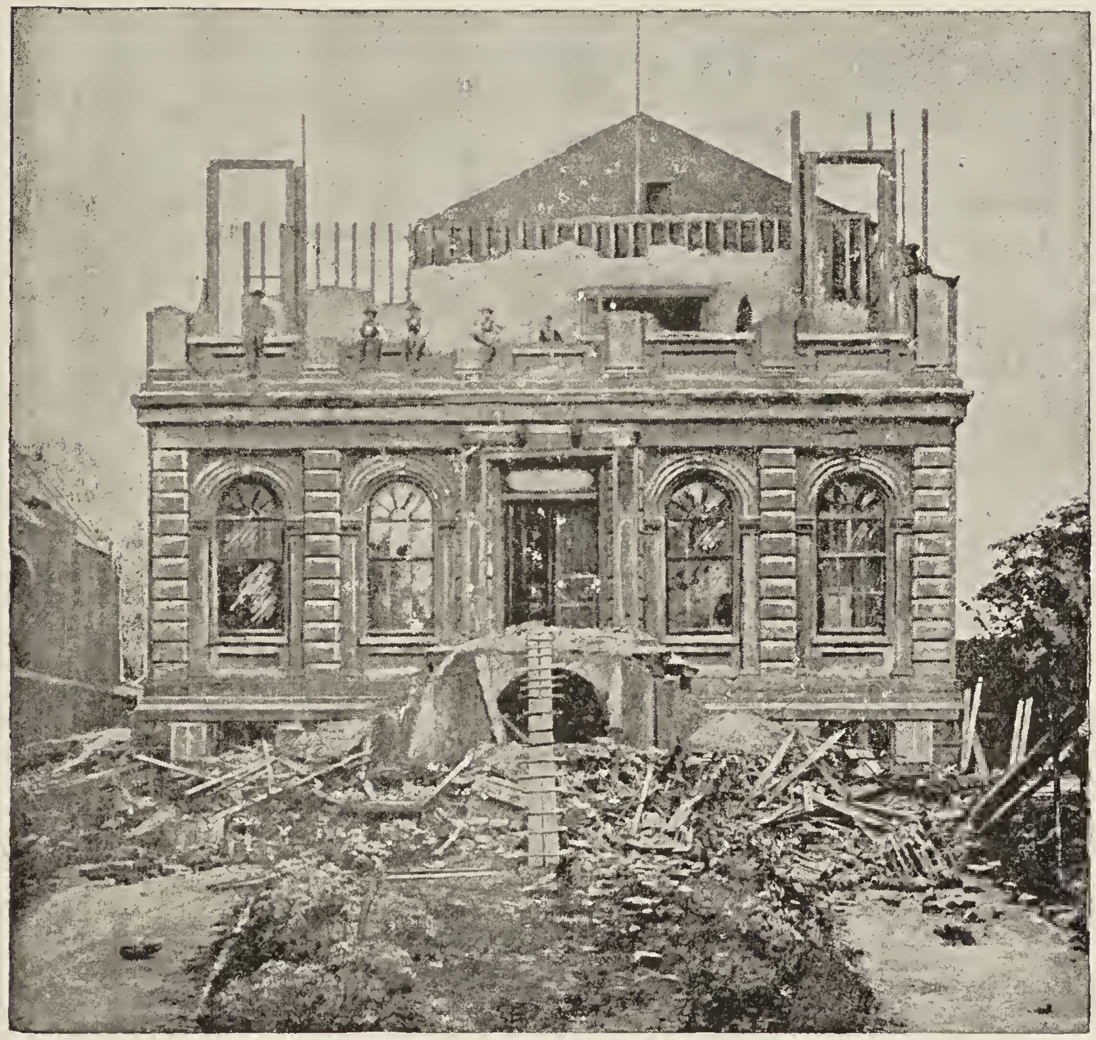


Fig. 3. The government building.

These three are the only government and public buildings; but as there was much prosperity in the province of South Carolina under the Crown, sufficient wealth was soon accumulated by the citizens of Charleston to enable them to erect dwellings which were in no way inferior in point of solidity to either the churches or other

buildings which were the property of the government. In addition to the professional and mercantile classes, many of the large planters made Charleston their home during at least half of the year, and most of their dwellings were durably and solidly built.

Among the most important of the private residences still standing are a large house on the west side of Beden's alley, long ago abandoned by fashionable occupants; several in Church street, between South Battery and Broad, among which may be mentioned the Heyward house, occupied by General Washington when he visited Charleston in 1791, a large double house on the south side of Broad street, numbered 85 and 87, with arched carriage-way in the center; the Smith block, in Meeting street, between the court-house and Hibernian Hall; and the large dwelling in Court-house Square, built originally by the Blake family; also the Pringle residence, in King street, which excited the admiration of Mr. Josiah Quincy, of Boston, when he was entertained there, a few years before the Revolution, by its owner, Mr. Miles Brewton. The Elliott mansion, on the west side of Meeting street, north of Queen, was one of the most pleasing of the time in its exterior, but it was destroyed in the great fire of December, 1861.

All of these houses are known to have been built before the Revolution, and so English was their appearance, that, in the case of Smith row before its interior was burnt out in the same fire, it resembled exactly, with its small wooden balconies attached to the second floor, dozens of houses that can be seen in London at the present day on the thoroughfares leading from St. Paul's to the Bank of England. They are all built with thick walls, and the bond by which they are held together is, in the language of the mason, the "Flemish bond" on the front and sides and the "English bond" on the rear. This latter is not as ornamental as the first, but is equally strong.

Upon examining the interior parts of these walls, which have been exposed for purposes of repair, it can easily be seen how thorough the work was; there being complete adhesion between the bricks and the mortar in which they were laid. The entire walls, when completed, were put together compactly, and have stood for over a century as monuments of the substantial and honest work of the time. The bricks were not the smooth machine-pressed bricks of the present, but were made by hand, and, the surfaces being somewhat rough, the mortar adhered with greater tenacity. They were all selected from the kilns, and were known by the dealers as the Carolina gray brick. Their manufacture has entirely ceased for some years. They much resembled the brick seen in the older parts of London.

But excellent as their quality was, and carefully as they were laid in the mortar during the progress of the work, the durable charac-

ter of the walls was probably due more to the lime from which the mortar was made than to the bricks themselves. This lime was invariably made from oyster shells, which were gathered at the mouths of the various rivers and inlets bordering the coast, where they are washed up by the action of the water, and sorted out into layers of different sizes by the tides and currents, in such a way as to render it possible to obtain quantities of any uniform size that may be wanted. The industry of burning lime from shells was an important one, and continued so until the cheaper stone limes from the Northern States were introduced, and the home-made article gradually was driven out of the market. This did not occur, however, until about the year 1838; and during the closing years of the last century, as well as during almost the entire first half of the present, whenever a brick dwelling was to be built, the owner of which was able to use the best material, it was invariably the rule that the brick chosen was the gray brick above described, that the mortar was made from shell lime, and that the bonds of the masonry were the Flemish and the English bonds. There are many specimens still standing in various parts of the city of this substantial work, consisting of houses erected up to the date above stated, any one of which can be recognized at a glance by those acquainted with their appearance.

The change by which stone lime was substituted for shell lime, and a different bond adopted in the brick work, was brought about by a public disaster as follows: In the year 1838 there was a conflagration in Charleston, which destroyed a large portion of the most populous part of the city. The number of wooden houses included in the conflagration was so great, that a law was soon after passed prohibiting the erection of wooden buildings within the fire limits, and as there was in consequence great activity in rebuilding of brick, there came from the Northern cities large numbers of bricklayers and builders in search of work and of contracts. It was these who brought with them new notions as to the best bond in masonry, and as to the most available lime to be obtained immediately and in large quantities.

The new bond, that had already prevailed for some years in the North, consisted of five courses of bricks lying lengthwise, and known as stretchers, with one course laid crosswise, known as headers; this process being repeated until the summit of the wall was reached. It is a very strong bond, and is the one which at present is almost universally used. Experts consider that a wall built with this new bond is less liable to crack than one built with the Flemish bond, but that it is next to impossible to split a wall built with the Flemish bond.

There is more opportunity for slovenly work, however, in the new bond, as any one can see who will take the trouble to notice the progress of brick-work at present which is not properly supervised.

In the Flemish and English bonds every course has to be finished before the next is laid, and there is little opportunity for any bricks to be in a wall unless they are completely surrounded with mortar.

If there lingers any doubt as to the superior hardness and tenacity of mortar made of shell lime, the doubter is referred to a fragment of sidewalk pavement in front of Dr. William Huger's residence, on the north side of Broad street. These bricks were laid at least fifty years ago. They are much worn, while the layers of mortar between them are so little worn, that they project in ridges above the bricks. The bricklayers who have come from other cities, and have been employed to demolish damaged portions of these old walls, complain of their hardness and of the difficulty of detaching the bricks entire.

It should be added that, owing to the deceptions that can be practiced by bricklayers in laying the new bond, an infinite amount of bad work has been done of late years. In one building which had to be leveled to the ground after the shock of August 31, in consequence of damage received, there were counted on the inner side of one of the walls nineteen courses of stretchers without a single course of headers, and the same shock played havoc with the foundations and cistern walls of many little wooden houses which had been built in the same cheap and unworkmanlike manner. There are many honorable and marked exceptions to this rule which need not be specified. They are due to honest work and careful supervision.

These details about bricklaying might appear foreign to the subject in hand, namely, a narrative of the Charleston earthquake. But they are essential to its being properly understood, and the violence of the earth movement will be the better realized when it is explained that some of these walls, which rival the masonry of old Rome in their solidity, were forced to yield to the severity of the great shock.

In the early summer of 1886, during the month of June and even earlier, several little tremors occurred; but did not excite much attention. During the sitting of the United States court in Charleston in that month there was a decided rattling of the sashes in the court room which excited observation, and which was thought by some to have been produced by some other cause than passing wagons or a boiler explosion. A well-known citizen has related that during the same month, while seated in his library in a rocking-chair, he was slightly thumped by an earth movement, but it made only a light impression upon him at the time. There were several other slight disturbances noticed by different people, which have become interesting since, in consequence of what occurred afterwards. They are all well authenticated, and show that the more serious shocks were preceded for many weeks by smaller preliminary ones, which were not distinctly identified at the time.

It is probable that these indications of what was coming were more


Town Creek
C O O
GAS WORKS
LIBERTY TREE 1765-66.
WHARF
CONCORD ST.
INSPECTION
MARSH
VERNON
WASHINGTON
EAST BAY
ALEXANDER
ELIZABETH
CHARLOTTE
HENRIETTA ST.
BOUNDARY
MARION SQUARE
HUDSON ST.
JOHN
MEETING
KING
ST. PHILLIPS ST.
COMING
JASPER
RADCLIFFE
WARREN
VANDERHORST
THOMAS
MORRIS
MARION PLACE
SMITH
FELIX
CANNON
SPRING ST.
BEE ST.
ASHLEY
RUTLEDGE
SERES ST.
ROCK
LAUREL
PERCY
BOIGARD
LANE
PARK
SHEPPARD
LINE
FISHBURNE ST.
MOUNT ST.
CONGRESS ST.
HUGER
MOULTRIE
RACE
AVE.
GROVE
POINSETT ST.
GROVE ST.
BUTLER ST.
HILL
STEWART
JOHNSTONE
HARRIS
JACKSON
LEE
COOPER
COLUMBUS
HANOVER
AMERICA
THE MALL
BLAKE
DRAKE
BAY
AMHERST
SOUTH
MARY
WASHINGTON


MAP OF THE CITY OF CHARLESTON.

distinct at the village of Summerville, about twenty miles from Charleston, on the line of the railroad to Augusta, Ga., and more distinct still at "Ten Mile Hill," on the same railroad; as both those places, especially the first, were afterwards the scenes of vertical thrusts. Nothing has been reported, however, from either place indicating the occurrence of such preliminary movements.

The first decided shock was felt at Summerville on the morning of August 27, but it was not noticed in Charleston. The next day, the 28th, another shock was felt at Summerville at 4.45 a. m., and it was distinctly felt at Charleston at the same hour, and during the day there were several other shocks at Summerville. The movement at Charleston consisted of a slight rocking of houses and rattling of windows.

Although the shocks at Summerville excited uneasiness in Charleston, no one was prepared for what followed. During the afternoon of August 31, between 5 o'clock and sunset, the atmosphere was unusually sultry and quiet, the breeze from the ocean that usually accompanies the rising tide was almost entirely absent, and the setting of the sun was followed by a glow which was only slightly noticeable. As the hour of 9.50 was reached there was suddenly heard a rushing, roaring sound compared by some to a train of cars at no great distance, by others to a clatter produced by two or more omnibuses moving at a rapid rate over a paved street; by others again to an escape of steam from a boiler. It was followed immediately by a thumping and beating of the earth underneath the houses, which rocked and swayed to and fro. Furniture was violently moved and dashed to the floor, pictures were swung from the walls and in some cases completely turned with their backs to the front, and every movable thing was thrown into extraordinary convulsions. The greatest intensity of the shock is considered to have been during the first half, and it was probably then, during the period of the greatest sway, that so many chimneys were broken off at the junction with the roof. The number was afterwards counted and found to be almost 14,000.

The duration of this severe shock is thought to have been from thirty-five to forty seconds. The impression produced upon many was that it could be subdivided into three distinct movements, while others again were of the opinion that it was one continuous movement or succession of waves, with the period of greatest intensity, as already stated, during the first half of its duration.

The first impulse with every one, as soon as the severity of the shock was realized, was to leave the house immediately, and seek a place of safety either on the street pavement outside, or on some part of the premises at a safe distance from the risk of falling walls. There were some remarkable escapes from the falling of two piazzas, one above the other, which were detached by the rocking of the brick

walls; but in a few cases persons attempting to escape were fatally injured before they could reach a safe refuge. The total loss of life, including wounded who afterwards died, was about sixty. It is probable that, if the shock had occurred during the business hours of the day, the falling chimneys would have caused many more casualties.

The sight that met the eyes of many as they emerged into the street was a cloud of white dust. This, it is thought, was produced by the overthrow of the chimneys, as the violence with which these were hurled to the ground was so great as to cause almost every brick to be loosened from its neighbors, and only in a few exceptional cases, where the masonry was of the durable kind already described, were there two bricks adhering together after the fall. The dry mortar thus wrenched from the walls rose in whitish clouds, which were a conspicuous feature of the occasion.

Many persons escaped injury by being asleep in bed when the shock occurred, and others by being prevented by various causes from escaping immediately, and consequently allowing the necessary time for the chimneys to reach the ground before effecting an exit from their houses. Great alarm was experienced by every one. Although there were many instances of apparent composure, especially among heads of families, due principally to the care for others, there were, nevertheless, many strong men who were completely unnerved by the events of that night, and who for weeks afterwards could not be induced to return to their houses between sunset and sunrise.

Tents for a few weeks were in great demand, and the supply sent on from Washington was soon exhausted. Most of the open spaces in various parts of the city were dotted over with these, and wooden shanties were hastily put up by the authorities on Marion Square and Hampstead Mall, for the accommodation of the destitute. Washington Square exhibited a scene which can never be forgotten. The colored people were allowed to erect shelters composed of any kind of material that they could get hold of, and the whole of the east half of the square was in a few days completely concealed from sight by the heterogeneous collection of pieces of boards and scantlings, pieces of old sails, bedquilts, carpets, and canvas. The quantities of battered tin—fragments of roofing saved by the negroes from the cyclone of the year before,—which were brought to light as material for protecting this extemporized earthquake quarter from the weather, exhibited their thrift in a most commendable way. (Pl. VII.)

No change whatever was produced in the atmosphere by the earthquake. Everything remained as quiet as during the afternoon and early evening. Scarcely a cloud was to be seen, and the stars continued to shine brightly until morning. Several fires broke out immediately after the shock, caused by the upsetting of oil lamps.

Flames and smoke from these arose immediately, but there was delay in the engines reaching the fires owing to some of the engine houses having been damaged, and further delay was caused by an obstruction to the valve of the water-works. In this emergency the old system of fire-wells, which preceded the modern supply, came into use again most opportunely. The fires did not spread much, owing to the absence of wind, and shortly after midnight, the pressure at the water-works having been re-established, the last vestige of fire was extinguished.

The city of Charleston is accustomed to early bed hours during the summer months, and at the hour of 9.50 many persons were in the act of retiring, while many others had already retired. Certain amusing incidents were the consequence of this; but, as events turned out, many lives were probably saved by the necessary delays in escaping, and there appears to have been no case of serious injury by wardrobes and other heavy furniture falling upon persons already in bed. Many who were asleep were awakened by the shock and remained in bed as they were, preferring thus to accept whatever fate was in store for them rather than risk being crushed by falling walls.

Considerable uneasiness was felt by many, as groups collected in the streets, for fear of another and more severe shock, and the few who seemed informed inquired from those who had been near the harbor whether the tide had reached its height believing that after high tide the risks of another shock would be less. For some nights afterwards the time of high tide was looked forward to with anxiety, for fear of something occurring before it was reached, but there seems to have been no connection between the two. There was a marked difference in the degree of alarm exhibited by the whites and blacks during the first night. The former, although extremely terrified, yielded very little to any outward exhibition of emotion, and seemed to regard the event as belonging to the order of nature, while the latter were absorbed in prayer during the continuance of the minor shocks, and, under the belief that this was a punishment visited upon them for their sins, were incessant in their calls upon the Almighty to spare them from further ruin. Among the incidents of the night were the prayer meetings extemporized by the blacks in the public squares, and the melodious voices of numbers singing together could be heard at considerable distances until morning.

After the severe shocks were over there was comparative quiet throughout the city that night, with the exception of the colored prayer meetings. Many carriages were observed moving in various directions. Some of these took to the homes of citizens a large number of excursionists from the mountains, and some were employed to move families to the Battery and other open spaces. The total number of shocks during the night is considered to have been eight.

It is difficult to describe one's sensations during an earthquake. An overpowering feeling with many was not to return to the scene of so much terror and alarm, and the next evening very few were inclined to take shelter in their homes. We are told that all English-speaking peoples regard their houses as their castles; but in this instance there was a sad change in our affections for the time being. Any noises produced by agencies which are new to us and not understood, especially if accompanied by serious tremblings of the earth, are calculated to fill us with apprehension. With the exception of sounds produced by the falling of a mighty cataract or the boiling of an impetuous torrent, what we hear at night is usually caused by the animal life that surrounds us. During lonely watches in tropical regions the roar of the lion or the hoarse growl of the jaguar are understood and can be provided against. The cause and the effect are intimately associated in our minds. But in a great earthquake shock the entire absence of a perceptible cause for the noise, and especially the utter stillness that follows, are unusual and appalling. It would appear as it approaches to be a terrible monster, who is moving everything before him in his strength, but to our dismay it proves to be convulsions into which the envelope of this small and feeble earth has been wrought by agencies almost unknown to us.

In the course of the following day the writer visited the principal thoroughfares below Calhoun street, to observe the amount of damage that had been done. He found great destruction to dwellings on East Battery, especially the two Ravenel houses, the others apparently not having suffered as much. Meeting street from South Battery to Broad street had received a good deal of injury, St. Michael's Church, the First Presbyterian or Scotch Church, and the Smith and Adger dwellings being almost destroyed. The guard-house seemed to be a mass of ruins, the conrt-house was much cracked, with one of the gables leaning out, and the entire portico of Hibernian Hall was demolished. The Fire-Proof building was much injured, though built mainly of stone; the blocks on and near the top were loosened and several stone steps on the east side of the northern porch were cracked. Broad street from Church street to the Post-Office contained a mass of débris thrown from houses on each side, mainly on the south. The entire sidewalks and roadway were impassable at intervals, and the curions who had collected to see the ruins were grouped in the middle of the street. The parapet or cornice of the front of The News and Courier building, composed of heavy blocks of granite, had fallen to the pavement, and the corner of the Chamber of Commerce building had received much damage. The Post-Office, an old colonial structure, built in the substantial manner of that period, had been much shaken, and its appearance was menacing. St. Philip's Church appeared to

have been more damaged on the outside than St. Michael's, the three porches on the front and sides being cracked and displaced, and half of the masonry of the highest part of the steeple (constructed of bricks) had fallen away and broken through the roof. The walls and interior seemed almost as much injured as those of St. Michael's. (Pl. XVI.)

Many brick buildings seemed uninjured, although subsequent inspection showed that they required repairs. The real amount of damage was not ascertained until weeks afterwards. The uneven way in which the violence of the great shock was distributed was strikingly exhibited by several instances of well-built houses having been damaged, while alongside of them were others known to be of flimsy material which escaped altogether. The minor shocks which followed at irregular intervals for three months contributed materially to render repairs necessary which it seemed on the first day would not be required. In this connection it may be mentioned that early in the month of November I was on the fourth floor (counting the basement as the first) of the Memminger School building, on St. Philip street, between the hours of 12 and 1 p. m., when a tremor or shake commenced which was peculiar and noteworthy. It consisted of what appeared to be a succession of low waves, following each other at regular intervals, and coming from a westerly direction. At first the large building, which is entirely isolated, began to move in a confused manner, but after a few moments the movement resolved itself into a regular oscillation from west to east. I was alone in the building, and not feeling under the necessity of displaying my nerve, I was strongly tempted to make a rapid exit by the stairs. I resisted the impulse, however, and as I stood near a south window looking out at two tall chimneys a short distance off, which had survived the great shock, and which I expected every moment to see topple over, I could measure with my eye the amount of sway of the window case immediately in front of me. This I estimated to be about one inch. This tremor was an unusually long and regular one, lasting about thirty seconds. The amount of oscillation imparted to a brick building by such a long-continued movement I should consider most detrimental, and sufficient not only to increase the damage already done, but also to thoroughly loosen many bricks which had been firmly embedded in the mortar.

In continuation of the description of the appearance of the city after the first day, it should be added that the Market Hall and several fronts to adjacent stores were much damaged, and throughout the remainder of Meeting street, as far as Calhoun street, were evidences of injury at intervals, including coping on the front of the Charleston Hotel. Along King street above Queen street the damage was by no means great, and the escape from injury of houses on that thoroughfare was very noticeable. (Pl. XIV.) The College

of Charleston building had its wings dreadfully shaken, and it was found necessary afterward to level them both to the ground. The shock was of great violence there, but the wings had been of recent and inferior masonry, while the central building, whose north and south walls were both forced outwards, had been substantially built. The date of the construction of the central building was the year 1828, previous to the abandonment of shell lime. This injury to the central portion indicates that the severity of the shock must have been greater at the college than either at the jail, work-house, or Roper Hospital, as these last were of recent work and erected without proper supervision. Their destruction was thorough and com-

Fig. 4. Charleston Medical College.

plete, and the jail and work-house have since been entirely demolished. The new portion of the Medical College, erected about the year 1855, was entirely destroyed, leaving intact the original building, of much older work. Three of the columns of the portico, of old brick-work, however, were thrown down also. (Fig. 4.) The Unitarian Church presented another illustration of the difficulty of joining the masonry of two different epochs. The original building stood well, but the modern additions fell away or became loosened.

On East Bay many stores and store fronts suffered greatly, and the upper layers of stone blocks on the Custom-House were detached in a manner similar to what occurred at the Fire-Proof building.

Above Calhoun street the large Orphan House building was not much injured, and the Citadel building required some repairs, which

were completed in time for the re-opening of the Military Academy. The granite foundations of the Calhoun monument, which were already several feet above the soil, were totally uninjured. The piling here had been very thorough, and although it is possible that the shock may not have been of great violence at this spot, those in charge of the work nevertheless feel amply compensated by the results for the care with which the details were supervised.

There was much injury done to the various buildings belonging to the gas works. The site of the works was originally low and muddy, and the foundations had been extensively piled. All of the walls except that around the pit in which lies the large gas receiver were more or less cracked, and the direction of the earth wave from northwest to southeast was made evident in the morning by a vacant space or fissure between the southeast face of the brick curbing of the pit and the adjacent soil. The width of the fissure was about eight inches. The entire brick lining of the well, with the gas receiver within and above, had evidently been moved from northwest to southeast eight inches and had returned to its original position. The strength of a circle of masonry with earth pressing against it all around was strikingly exhibited here. It is doubtless an illustration in a modified form of the principles of the arch. Everything about the gas works is usually kept in excellent condition, but the masonry of the walls can not be cited as belonging to the period that antedated stone lime.

The large cotton-factory building was very slightly injured. It was deemed necessary while erecting it to pile carefully its foundations, and its immunity from cracked walls is certainly due to that precaution.

With regard to the wooden houses little need be said. They were as much swayed to and fro as the brick ones, and their chimneys were snapped off with as few exceptions. A well-braced wooden house, with all the parts carefully pinned together, forms a compact and elastic whole, which, it is obvious, tends to return to its normal state as soon as the disturbing cause has passed, although in most instances there are displacements either of parts or of the whole which will be observed upon careful examination. Those parts of wooden houses which can not be secured as carefully as the outer frame, such as the attachment of the flights of steps to the various landings, were strained in many cases. Only a few were made uninhabitable by the shock, and inferior work was mainly the cause of this. But even those best built are now loose at their joints, easily shaken by passing vehicles, and somewhat out of plumb.

As proof that small wooden houses are the best suited to earthquake regions, it was stated, without, however, having been fully authenticated, that a certain colored family, living in a one-story wooden house near the northern limit of the city, were not aroused

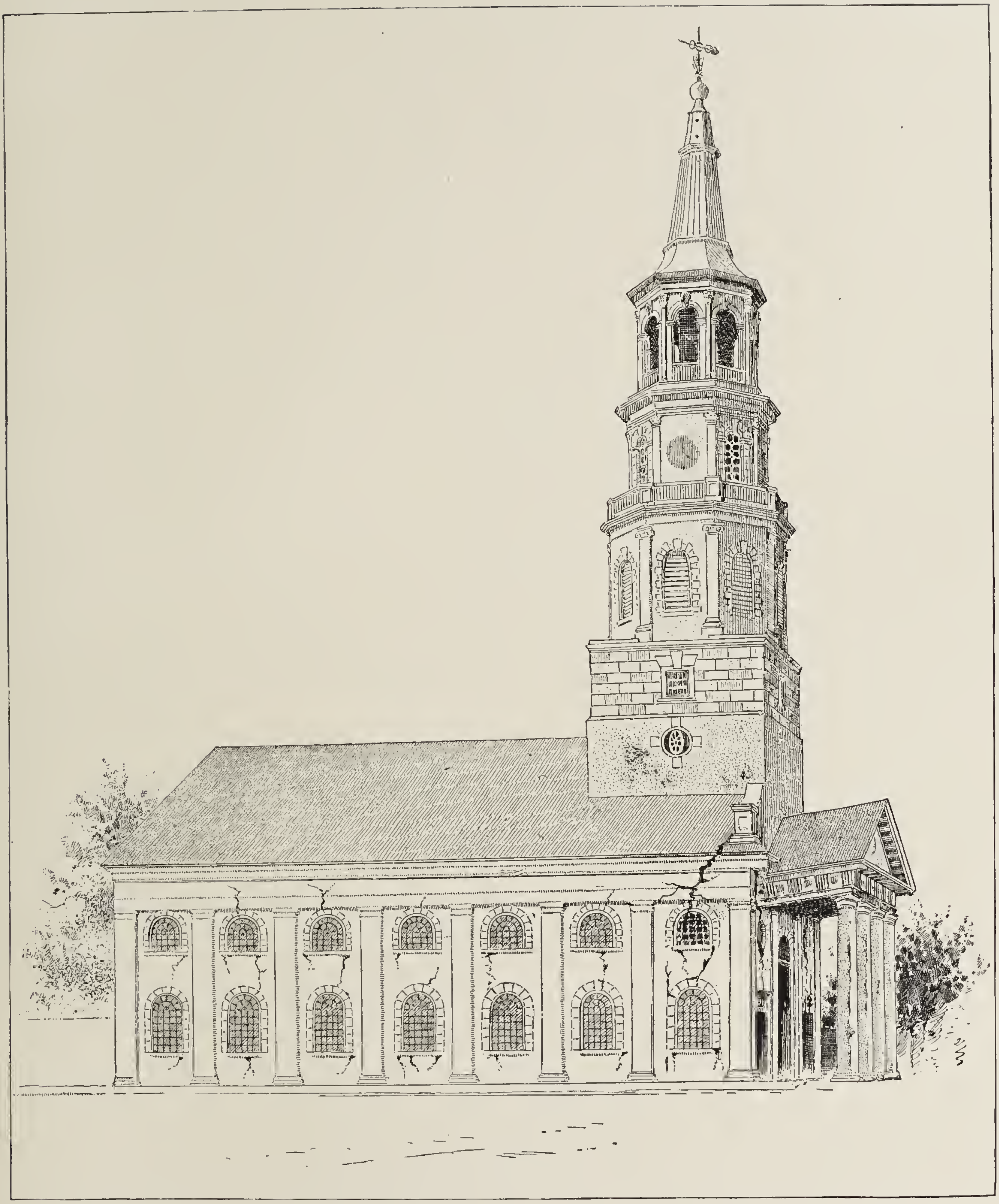
during that night, and were not aware of what had occurred until the usual hour of awakening the next morning.

When the work of restoration was fully commenced, such an amount of damage was revealed that the total sums up vastly more than was at first thought probable. This may be due in part to the subsequent minor shocks, which continued to recur until January, resulting in a further loosening of bricks which had not been started by the great shock. This slow manifestation of the degree of injury sustained, which was shared by some of the best-built brick houses as well as by many of the inferior ones, is surely sufficient to place the Charleston earthquake next to the New Madrid disturbance in the classification of Professor Shaler, although the vertical thrusts and consequent wave motions, with the many tremors that intervened, produced only fissures in the earth and no subsidences, as occurred after the New Madrid shock.

Having made the distinction between the quality of the masonry of the colonial period and of the period following the Revolution up to the year 1838, and the quality of a large proportion of the brick-work that has been done in the city of Charleston since then, it is proper that other instances be given to prove more clearly the difference in the durability of the work of the two periods. This can be done by referring again to the two churches St. Michael's and St. Philip's, and an account of what happened to them will be found interesting. (Pls. X and XVI.)

The first of these churches was built between 1750 and 1755. As already stated, both were erected on sites which were the highest available in the narrow limits of the infant city. No piles were driven for the foundation of the steeple of St. Michael's. The architect superintending the repairs, Mr. Gourdin, thinks the probabilities are that the builders were satisfied with the clay substratum, which was reached after excavating to the depth of eight or ten feet. They were certainly justified in coming to this conclusion, as the steeple has stood for over a century all the effects of time, except such an unusual commotion as was not contemplated by the builders. It is to be understood, too, that at that early day the mortar and bricks used were wholly the substantial and durable materials which have been carefully described. There were no others to be had, and an examination of the walls to-day proves their use beyond a doubt.

In the case of St. Philip's Church, it must be again explained that the present building is a recent one, although it so happened that the church and tower were finished in 1838, and that all of the parts were built of the same kind of materials and in the same manner as St. Michael's. This was just within the period that preceded the introduction of stone lime from the Northern cities. There are persons living who recollect when St. Philip's Church was rebuilt, and there-



ST. MICHAEL'S CHURCH.

fore it has not been necessary to dig under the foundation walls to ascertain whether piles are there, for it is perfectly well remembered that, in anticipation of a steeple being added to the tower at a subsequent date, the foundations of the latter were carefully piled. This seems to have been done as a matter of precaution, as it had been ascertained that the stratum of clay underneath the surface was not more than five or six feet thick; a fact which possibly the builders of St. Michael's had not ascertained, or, if they had, did not consider it important. There is, however, a difference in respect to the brick-work on the two steeples, which must be borne in mind in order to see that they illustrate the qualities of the masonry of the two periods. The entire brick-work of the steeple of St. Michael's is of the early period, whereas only the square tower of St. Philip's steeple is of that period; the remainder being of the second period, and built with mortar made of stone lime. This was in consequence of the upper portions of the steeple having been added about ten years after the church and tower had been built, and when the home-made lime had been driven out of the market by the imported article.

It must be explained that the brick portion of St. Philip's is much higher from the ground, probably forty feet, than the same part of St. Michael's, which would cause its oscillation to be greater. Both seem to have been exposed to a succession of earth waves of equal violence, judging from the amount of damage done. Both steeples probably rocked from east to west, or vice versa, and as a result St. Michael's was found next morning to have sunk eight inches into the ground,[1] without, however, any of the masonry having been seriously damaged, while St. Philip's steeple remained at the same level, but a large quantity of the inferior masonry at the top had fallen away, loosened by the rocking motion.

The rocking had caused the one to settle gradually in its unpiled bed, and the other to suffer no sinking in consequence of its unpiled foundation.

The question as to the direction from which the force appeared to come has been so often asked with unsatisfactory replies, that it seems impossible to obtain a general agreement of opinion on the subject. The cause of this may be the facts noticed by members of the U. S. Geological Survey, who made investigations immediately after the 31st of August in the areas most affected—that there were three loci[2] of limited extent where the movements were vertical, and from which waves spread in all directions, exactly as they do

[1] St. Michael's steeple did not settle evenly in its new bed, as it now leans some what to the northwest. It is probable that if it had been a tower, the greater weight above would have made it lean more, and what has occurred in this case may be the explanation of the leaning of the Tower of Pisa.

[2] The first investigations in the epicentral tracts seemed to indicate the existence of three epicentra and this opinion was expressed. Subsequent investigation has convinced me that there were but two.—C. E. D.

on water after pebbles have been thrown in. There may have been a crossing of waves and of sounds coming from these separate centers, which would account for the diversity of opinion as to the directions from which they came. The sounds also, traveling in every direction over the water around the city and becoming separated from the earth movements, caused every kind of opinion to be expressed as to direction.

There seems to have been unanimity of impression however as to the movement in the city of Charleston itself having been in the nature of waves. The writer will here offer his experience or observations on that particular point, which may be of value.

On the night of August 31 I was seated in a basement room of my dwelling, the floor of which is about eighteen inches above the surrounding soil, engaged in a game of chess. A member of the household was seated at a west window of the same room, about twenty feet from me. He heard the rumbling sound of the approaching shock coming over the water, and, in alarm, he immediately left the room through a door at the opposite or east side; the two players, being so absorbed in the game that they had not heard the noise, still remained seated. At that moment the wave reached the house, and, its violence being unexpectedly great, the oil lamp on the table was immediately extinguished by myself, and all the occupants of the room ran out into an adjoining garden. There, at a safe distance from the dwelling, I stood facing northward towards the house, the movement not yet being over. I was obliged to spread my feet apart to avoid being upset by the waves passing under me. These were from three to four in number, and seemed to be about six inches high, but this estimate of height is probably excessive.

Upon examining next morning the spot where I had stood there were two fissures to be seen in the hard shell walk three-quarters of an inch wide and 18 inches apart, quite straight and parallel, and running in a direction about north and south, at right angles to the direction of the wave. In the garden beds other fissures were noticed somewhat wider, but none as straight as these. I was unable to divide the whole disturbance into three successive shocks. The movement appeared to me to be continuous, with a gradual diminution in violence, the greatest intensity being during the first half.

My residence is in the southwestern part of the city, immediately upon the waters of Ashley River. The tide was almost at its height and there was a complete calm, which had prevailed during the afternoon, and which I had particularly observed as I sat in my upper piazza until sunset gazing upon the water—the rising tide being usually accompanied by more or less breeze from the ocean. The sky was without a cloud and the stars were shining brightly. My impression as to the direction from which the waves came was that they reached me from a little south of west by the compass, and

HIBERNIAN HALL.

that they traveled to a little north of east. During the continuance of the shock I was not conscious of any noise under my feet.

There was one mud spout, or craterlet, worth mentioning in the yard of a house opposite my own which I examined next morning. The material thrown up was sand, that had been slightly discolored by admixture with mud. The diameter of the mass that had overflowed was three feet, with the top of the craterlet five inches high. The craterlet was three inches in diameter, and its edges were so clearly defined as to lead to the impression that after the sand had oozed out there was a quantity of gas that had escaped and which had continued to do so until the edges had dried and hardened. There was no indication of water having escaped in any quantity from this craterlet, and although it escaped in many other places and was probably a little warmer than the atmosphere, there is no positive evidence in any instance that it was hot.

The number of shocks, with their degrees of intensity, commencing with the introductory shock of August 27 and ending on the 30th of September, is as follows:

| Date. | Shocks. | Intensity. | Date. | Shocks. | Intensity. |
|---|---|---|---|---|---|
| Aug. 27, 1886 | 1 | Slight. | Sept. 8, 1886 | 1 | Slight. |
| 28 | 1 | Do. | 10 | 1 | Do. |
| 31 | 8 | Destructive. | 12 | 1 | Do. |
| Sept. 1 | 3 | Severe. | 15 | 2 | Moderate. |
| 2 | 3 | Do. | 21 | 1 | Severe. |
| 3 | 2 | Do. | 22 | 1 | Moderate—local. |
| 4 | 2 | Slight. | 27 | 1 | Severe. |
| 5 | 1 | Moderate. | 28 | 1 | Moderate. |
| 7 | 2 | Slight. | 30 | 1 | Slight. |

The most severe shock after the 31st of August was the one of September 3, at 11 p. m. Afterwards they diminished in violence, the last one observed to the present writing having been on the 18th of March, 1887.

Many occurred at Summerville which were scarcely felt in Charleston, and when they were noticed at both places they were usually more severe at Summerville—most of the shocks there having been vertical thrusts.

For weeks after the great shock, during the still hours of the night while lying awake in bed, curious sensations were distinctly perceptible, as though the crust of the earth were resting on a gelatinous mass in constant motion. These corresponded to the movements observed by the Italian seismologists by means of delicate instruments and described by them. The shocks gradually diminished in intensity after November, and cannot at present be noticed by the unaided senses.

## THE EARTHQUAKE AT CHARLESTON.

By Mr. F. R. Fisher.

Attached to the following report on the great earthquake which visited Charleston will be found a diagram (Pl. XIII) showing the buildings at No. 157 Wentworth street, where I was residing at the time.

The property is on the south side of the street, about halfway between Rutledge and Smith streets, on the west side of the city. An inspection of the city map, prepared to accompany Mayor Courtenay's centennial address, August 31, 1883, will show that the house does not stand on "made ground," but at the beginning of a point of solid ground which reaches southwest as far as the corner of Lynch and Beaufain streets—perhaps a little farther. In the rear, the made ground begins at the back fence; while in front it has its margin near the center of the opposite square.

The house faces about 25° 30′ west of north, as well as I remember from observations made when setting up my equatorial telescope, and I have drawn the points of the compass in the diagram on that basis.

My position (marked A in the diagram) was in the second-story piazza. I was seated in a rocking-chair, facing about west-southwest, and consequently well placed to observe the general motion not only of the building itself but of surrounding objects.

When the shock came, it was without preliminary rumble or noise of any kind that I heard; but I may easily have overlooked it, as there is a street-car line in front of the house and a curve at the corner. Going around this curve the cars make a noise which resembles distant thunder very much at times, and we were so used to it that we rarely noticed it. If the earthquake noise resembled this at all, I may readily have neglected to take note of it.

The first intimation I had of the shock was an intense *vertical* movement of exceedingly small period and extent. By period, I mean the time occupied by one complete rise and fall of the surface; and by extent, the actual amount of vertical displacement. The motion strongly resembled the sensation experienced when a cask or hogshead is rolled over a warehouse floor, only it was much more violent, because the vibrations were of shorter duration.

This was the first phase of the great shock. It came suddenly, without any small tremors, and was uniform in its character until *combined* with the violent rocking motion, which constituted the second phase and laid the city in ruins.

My watch indicated $9^{h}$ $50^{m}$ and some seconds as the beginning of the tremors; but what the seconds were I can not tell, as I had to

ROPER HOSPITAL.

read the dial by means of the glow from a cigarette. The watch was not wound that night, and as it ran down by morning, its error could not be ascertained. By actual counting of half seconds the first phase lasted from five to eight seconds; but I lost my count when the second phase came on, by reason of its startling nature and the effort to get my watch in my pocket and hold fast to my chair at the same time.

I have already mentioned that I was facing about west-southwest, and I make particular mention of this fact, because by the first impulse of the second phase my chair was thrown forward on its rockers. The motion was so violent that I was compelled to hold on with both hands, placing one foot against the balustrade before me. After this severe lurch I made an attempt to rise and go to the assistance of those within the house. This attempt failed because I was thrown down in my seat again, and in such a manner as to turn the chair more to the south and bring me facing more southwest. This backward movement tilted my chair on its left rocker. How high it was raised on its other side I can not say; possibly four or six inches, for it was nearly enough to upset me. After this I made another attempt with more success. By jumping to my feet and running the length of the piazza as fast as possible I managed to avoid being thrown down and gained the inside of the house, where all my attention was for a time absorbed in caring for the inmates.

I arrive at the duration of this second phase in the following manner, and the result confirms in a measure the estimate which I first made. This first estimate was about thirty seconds for the whole shock; but from my notes I afterwards estimated from thirty to thirty-five seconds from its beginning to its end.

There are in the city several very fine regulators in the possession of jewelers and railroads, and I selected three of these, which I was assured had been corrected by Washington time at noon of the 31st. Now the first phase of the earthquake was hardly of a character to stop any pendulum in the city, while the second phase was very marked in its character, and was especially remarkable for two maxima, one of which occurred at the very beginning of the rocking, and was inferior to the second, which occurred near the end. It was the second of these which threw down so many walls.

One of the regulators stopped at $9^h\ 51^m$, another at $9^h\ 51^m\ 20^s$, and the third did not stop at all. It was found in the morning with the case doors wide open, but keeping good time. Apparently its escapement had not missed a single beat of the pendulum.

It is natural to suppose that the two clocks which stopped did so at about the moment of greatest motion. The majority of ordinary good time-keepers, which were supposed to be correct, stopped at $9^h\ 51^m$.

I may be wrong, but I judge that the time of the first maximum was $9^h\ 51^m$, when it broke into the first or milder phase with such

sudden violence. This first severe lurch was not heavy enough, however, to overcome regulator number two, which continued to show the time until the second maximum stopped it.

The difference of time as indicated by these two dials was twenty seconds; add to this the five or eight seconds of the first phase and five or six seconds for the final tremors, and we shall have between thirty and thirty-five seconds for the duration of the entire shock. I say add five or six seconds for the final tremors, because it was just at the close of the second maximum that I left my seat, and I had hardly reached a front room in the house when the shaking ceased.

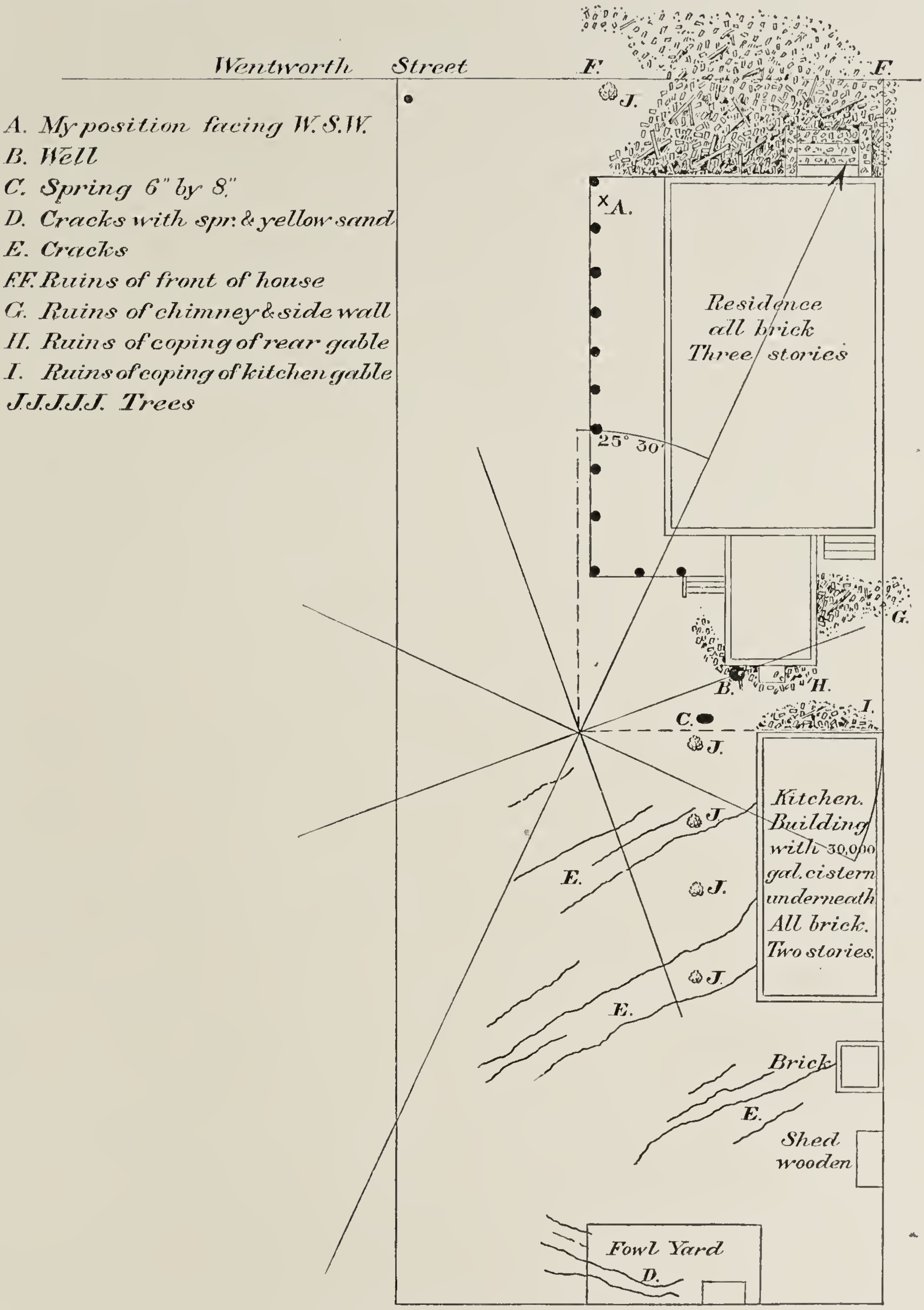
As to the direction of the great and subsequent shocks:

I have mentioned to some considerable extent the character of the tremors. In the first phase there was no direction noticeable, as the movement was small and vertical. Attention has also been drawn to the fact that when the second phase commenced it indicated itself by throwing the chair forward on its rockers in a west-southwest direction. I can not remember being thrown backward at first, and am certain had the impulse been in that direction I should have noticed it. Again, it will be remembered that in my first effort to rise I was turned more to the southwest. In this position I had a good view of the length of the piazza.

Regarding the rear of the house as the bow of a ship, the sensation of motion, the appearance of the piazza floor, and the walls of the house were similar in all respects to my experience when at sea with the vessel taking the billows a little aft the port bow, with the exception that the motion was more violent and abrupt. Doubtless had the rocking motion been confined to rocking alone the similarity would have been still more striking, but such was not the case; the vertical motion of the first phase did not terminate when the second phase began, but was mingled with it. As a result, the rocking motion had a peculiarly indescribable shivering element mixed with it. There is a sickening and giddy feeling attending this motion. Combined with the instinct of self-preservation and the desire to help others, while the ear is deafened by the sound of falling walls and the eye blinded by clouds of stinging dust, it makes the senses reel, and one finds it almost impossible to continue the analysis, even though the desire to see, hear, and feel all that is going on be as strong as ever. It required all my self-will to keep my head clear and act promptly in the cause of human life.

Bearing these items in mind, it seems to me that the direction of the first impulse and subsequent motion came from a point between east and southeast, but nearer to the former than the latter; and observations made after the shock serves to strengthen that opinion.

During the remainder of the night our party encamped on the spot marked K on the diagram, and I spent the time walking backward and forward between this point and the rear of the yard. I




PLAN OF F. R. FISHER'S RESIDENCE.

kept apart from the rest in order to observe better. Before the first shock I heard no noise, but previous to each subsequent shake there was a decided noise, which was proportional to the shock which followed. The rumble was about as long as the shake and generally merged into it. At times there were peculiar obscure detonations without perceptible tremor; and, on the other hand, I frequently heard an insecure door on an outbuilding rattle gently without any preliminary sound. The tremors which shook the door in this manner were not felt at all.

I am probably not mistaken as to the direction of these noises, which in every instance came up from the east-southeast. In order to see if I was right I noticed the people near me, and found them always listening in that direction.

Another evidence of the approximate direction I derive from a young lady who was in the house when the great shock came. She was standing before a hanging mirror, and her first impression was a tilting downward of the glass in front of her, and then the mirror swung out from the wall toward her. This mirror hung on the front wall of the house.

Because of the hard treatment that stopped the regulator, which indicated $9^h$ $51^m$ p. m., I was induced to examine it closely, to detect, if possible, what particular motion had influenced it the most. I thought if the shock had struck it at any considerable angle to the plane of its normal motion the pendulum would have made some mark or impression on the back or front of the case, as it weighs about seventy-five pounds. To this end I also examined the scale which measures the amplitude of the pendulum's vibrations, but I could not find that the pointer had touched it; neither could I detect any mark on the case. This is rather singular if the shocks came from the east or southeast, as the plane of the pendulum's motion lies about east-northeast and west-southwest; but it may be accounted for if we take into consideration the manner of suspension, which pr vents, to a certain extent, any considerable lateral motion.

The amount of rise and fall in the surface of the ground must have been very considerable if we judge by the effect on this pendulum. The bob is composed of two mercury cups, with the usual metallic caps. In each of these caps there is a hole, filled with a brass plug about one-eighth of an inch in diameter and three-eighths of an inch long. These plugs are fitted with the usual watchmaker's care—free to move, but having no play. The surface of the mercury was about an inch below the caps, and yet the plugs were thrown out and considerable mercury was projected through the holes and scattered on the bottom of the case.

I have also investigated the forces which acted upon and twisted certain chimneys, which were brought thereby into a singularly uniform position without being thrown down, and found the direction

of impulse to be in a plane about east and west. In these investigations I did not make allowance for the adhesion of the masonry at the foundation, but proceeded on the basis that they were bodies resting freely on their supports. Making this allowance for adhesion, it is to be assumed that the direction of the plane of impulse lies south of east.

Concerning the amplitude of the vibrations I can say nothing, as I was not well placed to estimate them. Had I been in the house, with numerous hanging objects around me, the case might have been different.

In the diagram it will be seen that the most ruin was wrought on the front of the house. The gable was thrown down, and the front as low down as the windows of the first floor bulged out. If the shocks came from the other side this was the weakest part of the house, as it had no support beyond. The same effect will be observed in the kitchen building.

There is a cellar under the extension in the rear of the main building or residence, and much trouble was experienced at one time in cementing it in such a way as to exclude a spring. This spring may be the source of that which burst out at a point marked C, and may also have some connection with the well at B. The hole made by it was oval in shape and measured six by eight inches. It did not flow for more than ten minutes, but discharged much water while it lasted. When I had a chance to go to it there was no more water coming from the orifice, and I could not ascertain whether it was cold or warm. There was no subsoil brought to the surface.

The cracks in the yard numbered about twenty, great and small, and they remained open. Some of them measured a half inch in width and varied from six inches to many feet in length. A few are prolonged into the next lot on the east side and beyond. None extended beyond the fence on the west side. Where they intersect the kitchen building the walls are found to be badly cracked, and open more at the foundation than higher up. One of these cracks afterwards widened considerably, as did also the corresponding crack in the ground.

I am inclined to the belief that two of these fissures are but the beginning of the two which split the west end of the Rodgers house, on the corner of Wentworth and Smith streets, though I could not actually trace them.

In the fowl-yard (see diagram) there were two short cracks, about eight and ten feet long and three-quarters of an inch wide, and from these issued another spring, which brought up yellow sand in quantities sufficient to make a mound four inches high and spreading over a considerable area. I did not discover this until morning. Probably the water did not flow for any great length of time. I had sup-

posed during the night that all the water in the yard came from the other spring.

These cracks all through the yard show much compression of the surface, although they remained open; for each one lies along a well-defined ridge which slopes away three or four feet on either side where they do not meet. That the surface of the ground has changed its level is evidenced by the cracks in the building, which are open at the ground but closed at the top of the wall.

The direction of the fissures, it will be noticed, is nearly northeast and southwest, with the exception of the two in the fowl-yard.

In closing this report, I wish to add an item in relation to the direction of the earthquake.

Owing to the ruinous condition of the interior of the house, it was not easy to make any observation on the subject of small articles which had been thrown down, except in a few instances. Out of twenty objects which I noted, sixteen were thrown in a general westerly direction to different distances. The remaining four lay as follows:

One was three feet from its former resting place in a northerly direction, but may have struck a chair and been landed on the spot where found, if it fell in the direction of the majority. The second, a group of bottles, fell to the east, as did the third and fourth.

In one room a cast-iron "summer piece" stood against the grate in the fire-place. This summer piece or apron was thrown a distance of five feet toward the west. The grate was unhooked by the shock and thrown four feet in the same direction. This will give some idea of the projectile power of the shock.

In this report I have confined myself solely to my own personal experience with regard to my immediate surroundings; and in one instance only have I digressed by giving the testimony of another, and I did this because it bore directly on the place under discussion. I have judged this essential, as it would require too much space and time to make a statement of all, or even of a part, of what I have heard from others, much of which is really of value.

## CHAPTER II.

### DETAILED EXAMINATION OF THE EFFECTS AT CHARLESTON.

The foregoing descriptions by citizens form a graphic picture of the earthquake at Charleston considered as a whole. It now remains to examine in some detail the more important of the component features. It will be necessary, however, to discuss the facts ingroups rather than one by one, for to describe them individually would protract the account unnecessarily.

The morning after the great disaster showed clearly that the havoc wrought by it had been very great. There was not a building in the city which had wholly escaped injury, and very few had escaped serious injury. The extent of the damage varied greatly, ranging from total demolition down to the loss of chimney tops and the dislodgment of more or less plastering. The number of buildings which were completely demolished and leveled to the ground was not great. But there were several hundred which lost a large portion of their walls. There were very many also which remained standing, but so badly shattered that public safety required that they should be pulled down altogether. There was not, so far as at present known, a brick or stone building which was not more or less cracked, and in most of them the cracks were a permanent disfigurement and a source of danger or inconvenience. A majority of them however were susceptible of repair by means of long bolts and tie-rods. But though the buildings might be made habitable and safe against any stresses that houses are liable to except fire and earthquake, the cracked walls, warped floors, distorted foundations, and patched plaster and stucco must remain as long as the buildings stand permanent eye-sores and sources of inconveniences. As soon as measures were taken to repair damages the amount of injury disclosed was greater than had at first appeared. Innumerable cracks which had before been unnoticed made their appearance. The bricks had "worked" in the embedding mortar and the mortar was disintegrated. The foundations were found to be badly shaken and their solidity was greatly impaired. Many buildings had suffered horizontal displacement; vertical supports were out of plumb; floors out of level; joints parted in the wood work; beams and joists badly wrenched and in some cases dislodged from their sockets. The wooden buildings in the northern part of the city usually exhibited externally few signs of the shaking they received except the

loss of chimney tops. Some of them had been horizontally moved upon their brick foundations, but none were overthrown. Within these houses the injuries were of the same general nature as within those of brick, though upon the whole not quite so severe.

The amount of injury varied much in different sections of the city from causes which seem to be attributable to the varying nature of the ground. The peninsula included between the Cooper and Ashley Rivers, upon which Charleston is built, was originally an irregular tract of comparatively high and dry land, invaded at many points of its boundary by inlets of low swampy ground or salt marsh. These inlets, as the city grew, were gradually filled up so as to be on about the same level as the higher ground. The distribution of these swampy inlets is well shown in the map of the city (Pl. IX) furnished to me by Mr. Earle Sloan. At present there is little to indicate to the eye the former existence of these low places, and we know of them only from the old maps of the city, which have been made from time to time during the last two centuries. As a general rule, though not without a considerable number of exceptions, the destruction was greater upon made ground than upon the original higher land. A marked instance of it is Calhoun street from King street to the Cooper River. This part of Calhoun street lies upon made ground, and there is hardly a building upon it which did not suffer very seriously; many were left in a condition little better than complete wrecks. The city gas works are situated not far from the end of this street upon the river front, and the brick walls were thrown out upon the southeastern side (Fig. 5), while the large chimney was broken across about twenty-five feet below the summit, the upper portion not falling, however, but being slightly displaced.[1] Market street from Meeting street to the Cooper River

[1] The following list of injuries to buildings in Calhoun street is taken from the Charleston Sunday News of September 5, 1886:

Corner Calhoun and Washington streets, Berkeley County Lumber and Railway Company, two-story brick building; first story down entirely. (Sic.)

No. 36 Calhoun street, brick building; kitchen fell down, killing a child.

No. 37, two and a half story brick building; gable down, piazza broken down, and building in a dangerous condition.

No. 39, brick; badly damaged with numerous cracks.

No. 41, corner Calhoun and East Bay streets, brick building; gable and back piazza fallen; numerous cracks; dangerous.

No. 50, two-story wooden building; chimney and roof fallen in.

No. 57, brick, two-story; roof displaced; brick cornice and walls seriously cracked.

Barnard's Row, corner Calhoun and Middle streets, six two-story brick buildings; seriously damaged and unsafe.

No. 98, two and a half story wood building; listed to one side; piazza smashed in.

No. 106, two-story wood; piazza broken in; house leaning to opposite side.

Emanuel African M. E. Church; walls listed; organ broken up; plastering down.

Mount Zion Presbyterian Church (colored), largest auditorium in Charleston; slightly damaged.

extends over the site of an old marsh in which ran a small stream. The ground is all made-ground. The buildings on both sides of the street were without exception severely injured, portions of many walls being thrown into the street and those left standing being badly cracked.

There is probably no street in Charleston where severe injury to buildings was more general than upon Market street. The square bounded by Queen, Mazyck, Franklin, and Magazine streets contains the South Carolina Medical College, the hospital buildings, and the county jail. Much of the square is made ground. All of the structures upon it, which are large and massive buildings, sustained unusual injury, and the Roper Hospital, which stands upon made ground, was very nearly a total wreck. Beaufain street, which extends largely over made ground, presented many houses which lost their fronts and were so badly cracked as to seem at first beyond repair. (Pl. XII.)

What has sometimes been called "the worst wreck in Charleston" occurred on Hayne street, immediately north of Market, where a block of buildings standing upon made ground was completely demolished. These instances might be greatly extended, and some of special interest will be found in Dr. Manigault's description of the earthquake. (Pl. XVII.)

On the other hand, severe injuries were by no means confined to artificial ground, for many serious disasters occurred where the ground was firmest. On Broad, King, and Meeting streets, which traverse the original high land through the greater part of their extent, many buildings lost their cornices and gables and many were severely cracked and fissured. (Pls. XIV and XV and Fig. 1.)

The larger and more massive structures, such as the public buildings, churches, and halls, were seriously injured, and required very extensive repairs before they could be rendered safe and suitable for further use. Among these the two Anglican churches St. Michael's[1]

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No. 106, two and a half story brick house; seriously damaged throughout; dangerous; is to be pulled down.

No. 122, wheelwright shops; badly damaged; both roofs down.

No. 130, two-story brick; front entirely dismantled; dangerous.

No. 132, two-story brick; an entire wreck; one person killed and two injured in the ruins.

[1] St. Michael's Church was built in 1752. It has a tower 168 feet in height, which formerly served as a conspicuous landmark both to incoming vessels from the sea and to the country round about. During the Revolutionary war its steeple was painted black, in order to obscure it from the British vessels of war. When the city was captured its chime of eight bells was taken down, carried to London, and sold; but by the liberality and good feeling of some London merchants it was purchased and restored to its place in the tower. St. Philip's Church was built somewhat earlier, was destroyed once by fire, and was rebuilt. In its church-yard lie the honored remains of Rutledge, Pinckney, Gadsden, and Calhoun. (Pl. X.)

ST. MICHAEL'S CHURCH AND VIEW DOWN MEETING STREET.

and St. Philip's are conspicuous by reason of their comparative age and the many historic associations connected with them. They are venerated by the people of Charleston as profoundly as the Old South Church by the people of Boston. The injuries to these buildings were of special interest. They are described by Dr. Manigault in the preceding chapter. So much cherished are these two churches that they have now been repaired at great cost and restored as nearly as possible to their original condition. The police station, a large, massive building in the Grecian style, situated at the corner of Broad and Meeting streets, lost its portico and a portion of its walls, and was severely cracked. (Pl. XV.) Hibernian Hall, a large building of similar style, on Meeting street, also lost its portico and was badly fissured. Nearly opposite to it the county records building, usually known as the Fire-Proof building, and constructed of sandstone, lost its north and south gables, besides being considerably cracked. The Court-House lost a portion of its roof and gables and its heavy walls were cracked in many places. The Charleston Hotel, on Meeting street, a large and heavily built quadrangle, with a portico of lofty columns, was riven with a great number of small cracks and a portion of the parapet in front fell to the pavement below. In Wentworth street the fine large hall of the German Artillery was nearly a complete wreck, the northwest and northeast corners having crumbled to the ground in ruins. In Archdale street the walls of the Unitarian Church were severely cracked, and the upper part of the tower was overthrown, falling with great ruin through the roof into the auditorium below. The Post-Office, an old but very substantially built structure, was severely shattered, and though its walls for the most part remained standing, it was necessary to shore them up to avert the danger of collapse. (Fig. 3.) The hospital buildings on Queen street were all much fractured, the Roper Hospital receiving the worst injuries. The buildings of the Charleston College were almost wrecked. The very large and massive buildings forming the Citadel and the military school on Marion Square were also severely injured, losing a part of their cornices and the towers at the corners being riven from the main walls by wide cracks and otherwise shattered.

To mention private houses which were nearly or quite ruined may be unnecessary. But in general terms it may be remarked that the residences of the wealthy and distinguished families of Charleston are more numerous in the extreme southern and southwestern than in other quarters of the city. Many of the houses are old and large, and give pleasing external indications of the culture of the generations which built them. Amid all the changes of fashion in domestic architecture, these old houses must still seem excellent examples of whatever is imperishable in the canons of good taste. They were built to endure by families which had an honorable

history, and which looked forward to their equally honorable perpetuation. Houses built at more recent periods in the same quarter are indicative of the same culture, and many of them are fine structures.

The injuries received by these dwellings have been in a very large number of instances most serious. Porticos, bay windows, and cornices have been demolished, wide cracks opened in the walls, arches crushed and broken, the interiors utterly ruined, and in not a few instances large portions of the fronts have been thrown into the streets. Many, however, escaped with damages which amount to nothing more than permanent disfigurement of the walls by cracks which are not dangerous, and the inevitable loss of plastering within, and they could be made habitable and comfortable with moderate expense.

The havoc wrought in the principal streets was also very great. Doubtless the most important is King street from Broad street to Marion Square. Near the corner of Broad a fire started a few minutes after the shock in a row of buildings extending nearly to the Quaker Cemetery and destroyed them. The remaining houses upon that block were severely cracked, and the upper portions of the walls of most of them were precipitated upon the pavement. From Queen street to Market the injury was also very great and of the same general character, though a considerable number of large structures appeared, externally at least, to have escaped serious damage. The Victoria Hotel and the Academy of Music, though terribly shaken and internally much injured, did not lose their walls.

Beyond Market the buildings opposite the Waverly Hotel were practically in ruins, the upper portions of their walls having been thrown to the ground. From Beaufain to Wentworth streets a fine block of stores fortunately escaped extreme injuries, though in some cases the cornices were thrown down. Here King street passes into firmer ground, and thence northward to Marion Square the graver injuries were confined to an occasional overthrow of walls and parapets and the invariable chaos of interiors. Meeting street is second only to King in importance. The injuries to some of the largest public buildings on this street have already been spoken of. There were still more serious damages to the stores, several of which were complete wrecks, losing their entire walls or suffering from fractures and dislocations which seemed at first beyond repair. Others received only minor injuries.

Cumberland street from Meeting to East Bay suffered very great damage, many fronts being thrown down and the buildings being left in a condition little better than wrecks. Broad street, one of the most important thoroughfares, likewise suffered greatly. The granite parapet of The News and Courier building was hurled to the


POLICE STATION, CORNER BROAD AND MEETING STREETS.

pavement and the heavy roof left in a precarious condition. The fronts of several commercial buildings were wholly thrown down, a still larger number lost their cornices, and all were cracked and their interiors thrown into dire confusion. East Bay street, which runs near and parallel to the Cooper River, and which is the site of the great shipping houses, also suffered severely. Several buildings were completely ruined; one at the corner of Cumberland street being tumbled to the ground.

In truth, there was no street in Charleston which did not receive injuries more or less similar to those just described. To mention them in detail would be wearisome and to no purpose. The general nature of the destruction may be summed up in comparatively few words. The destruction was not of that sweeping and unmitigated order which has befallen other cities, and in which every structure built of material other than wood has been either leveled completely to the earth in a chaos of broken rubble, beams, tiles, and planking, or left in a condition practically no better. On the contrary, a great majority of houses were left in a condition shattered, indeed, but still susceptible of being repaired. Undoubtedly there were very many which, if they alone had suffered, would never have been repaired at all, but would have been torn down and new structures built in their places; for no man likes to occupy a place of business which suffers by contrast with those of his equals. But when a common calamity falls upon all, and by its very magnitude and universality renders it difficult to procure the means of reconstruction, and where thousands suffer much alike, his action will be different. Thus a very large number of buildings were repaired which, if the injuries to them had been exceptional misfortunes instead of part of a common disaster, would have been replaced by new structures. Instances of total demolition were not common.

This is probably due, in some measure, to the stronger and more enduring character of the buildings in comparison with the rubble and adobe work of those cities and villages which are famous chiefly for the calamities which have befallen them. Still the fact remains that the violence of the quaking at Charleston, as indicated by the havoc wrought, was decidedly less than that which has brought ruin to other localities. The number of houses which escaped very serious injuries to their walls was rather large; but few are known to have escaped minor damages, such as small cracks, the loss of plastering, and broken chimney tops.

A careful study of the injuries to buildings in a city devastated by an earthquake generally enables us to obtain ideas, though imperfect ones, of the nature and characteristics of the forces which have wrought them. It therefore becomes a matter of interest to study these injuries with a view to ascertaining what were the pre-

vailing directions of the complex impulses which constituted the earthquake.

It did not take long to discover that the number of overthrown walls facing north and south exceeded those facing east and west. It soon appeared also that the injuries to buildings had some relation to the direction of the streets. It will be well, however, to glance at the map of the city and gain an idea of this. It will be seen that south of Beaufain street the directions are a few degrees west of north for those which run up and down the peninsula and a little south of west for those which run across it. At Beaufain street the directions of the principal streets undergo an abrupt change, the longitudinal ones extending about N. 30° W. the transverse ones W. 30° S. We may therefore, for immediate purposes, divide the city into two portions at Beaufain street, and the streets of the two divisions will thus form two networks differing in their directions. The preponderance of overthrown walls facing north and south is well marked in the southern division, but it is still more so in the northern. In those blocks which are solidly built up, without open spaces between buildings, the overthrows were decidedly more numerous on the transverse than upon the longitudinal streets.

The number of isolated or wholly detached houses is quite considerable in many parts of the city, and the liability to overthrow was in such cases independent of the direction of the street, and dependent wholly upon the plan of the building and the direction from which the disturbing force came. The continuously built-up blocks of Broad, Hayne, and Market streets, running east and west, had relatively more fronts and cornices thrown out than those of King and Meeting streets, which run north and south. Above Beaufain the destruction upon King and Meeting streets through thrown walls was small. In completely isolated buildings north and south walls were more frequently thrown than east and west ones. Moreover, the east and west walls disclosed in many cases some very significant injuries which appeared less frequently on the north and south ones.

When the buildings were three or more stories in height, and the windows of each story placed directly over those of the story below, the cracks in the walls exhibited a well-marked tendency to the following configuration: In the middle stories the portions of wall between the caps or lintels of lower windows and the sills of the windows above were often traversed by two diagonal intersecting cracks. But from the upper corners of the upper windows cracks extended almost vertically upwards to the summit of the wall. This configuration was so common as to attract universal attention, and it is well illustrated in Fig. 5. The meaning of it is plain. These diagonal cracks are the results of shearing stresses set up by a motion of the wall nearly or quite in its own plane.


ST. PHILIP'S CHURCH.

FIG. 5. Diagonal cracks between upper and lower windows.

These diagonal cracks are more numerous apparently in walls running north and south than in those having transverse directions, but their occurrence is still common in those running transversely.

Perhaps the most remarkable occurrence which can be selected as a test case was found at the city gas works. The great gasholder is supported upon a masonry foundation sunk in the ground, so as to form a wide, shallow, circular well. The whole mass of this great

FIG. 6. The city gas-works.

structure suffered horizontal oscillation, and the retaining earth inclosing the foundation was found to be separated from the masonry by a space of about eight inches on the southeast side and two inches on the northwest side; the direction indicated for this oscillation about S. 35° E. (Fig. 6.) The circular shape of the structure eliminates all causes inherent in the form or plan of the mass which would be liable to modify its movement or to deflect it in a direction different from that of the forces which moved it.

Another remarkable instance was one of the large wooden warehouses of the Northeastern Railroad Company, on the shore of Cooper


FIG. 7. Storehouse of Northeastern Railroad moved from its foundation.

River, in the northern part of the city. This structure is about four hundred feet long and rests upon piles. It was moved bodily in a direction about S. 30° E. through a distance of eight feet nine inches, and its southern end overhung its supports far enough to permit it to sag down about two feet. It contained about fifteen hundred tons of freight at the time. (Fig. 7.)

Mr. A. de Caradeuc, chief engineer of the South Carolina Railroad, also states that—

We have a pier or wharf on Cooper River 1,000 feet long on the river front and 100 feet in width, built on piles driven from forty to sixty feet below the surface of the mud. The structure is solidly built, with heavy timbers on these piles. Upon the floor we have erected eight large warehouses, the sills of which are simply laid on the floor. These warehouses were all slid on the floor, from six to eighteen inches in a southerly direction and from three to six inches in an easterly direction, without

losing the perpendicular of their upright posts, although nearly all the hanging braces were torn from their sockets. The roofs were entirely uninjured. Wholly independent of the wharf we have two large warehouses, 60 feet by 400, built upon piles, capped with heavy timbers. They were both partly filled with phosphate fertilizers, several thousand tons in each. One of these moved 10 feet southwardly from the caps and lies on the bare piles. The second bears every evidence of having been upheaved vertically not less than three inches; for many of the upright posts of the building which had fitted into three-inch sockets on the sills are now standing on the sills. There was no sinking of the piles.

There were other instances of the displacement of houses upon their foundations, but none so great as those described by Mr. de Caradeuc.

The monuments in graveyards have generally been carefully scrutinized after a great earthquake, as these seem at first to be well suited to disclose the directions of the impulses, and many of them are easily displaced. There are several churchyards and cemeteries in and about Charleston, and all of them were visited, with this inquiry in view. The result was utter bewilderment. The headstones were thrown in every conceivable direction, and the most careful comparison failed to disclose any predominant direction whatever.[1] The truth is that such monuments are not adapted to give decisive indications of direction of motion; for it is to be remembered that the impulses are always complex, and never simple. It will be a rare chance that the resultant of several impulses compounded will strike the base of the monument perpendicularly to any one side. Striking it obliquely, the shaft will be tilted in such a manner as to throw the whole weight of it for an instant upon one corner. The center of impact of the shaft then will not be vertically over this corner, and the result is a twisting motion.

Moreover, the direction of the resultant of several impulses compounded is continuously shifting with great rapidity. Still, if there are one or more impulses having a single direction and greatly exceeding in force and amplitude all impulses in any other direction, we might then expect to find the displacements of the monuments showing conformity to them. Probably this predominance sometimes occurs. At Charleston it certainly was not very pronounced.

In seeking to determine from the injuries to buildings the prevailing direction of motion, we find, therefore, that these injuries indicate no exclusive one. In every direction the movements had sufficient power to overthrow and destroy. But out of the mass of facts there appear some which indicate that the most energetic and destructive came from a direction somewhat west of north.

It seems proper to add here a class of testimony of a very differ-

[1] I have upon my files a large number of photographs and drawings of displaced monuments in cemeteries, but they give no result that is in the least degree intelligible, and I can find no reason for publishing them, unless it be to show their discordant character.

ent nature upon the subject of direction of motion. There were many persons whose letters are before me who assert that the most noticeable impulses came from the west, or a little south of west. They base their inferences wholly upon their sensations. A good example of this testimony is to be found in Dr. Manigault's narrative. After getting out of his house into the door yard he spread his feet apart and braced himself east and west to avoid being overthrown, and felt undulations of great amplitude passing under him in that direction.

The number of persons who, from direct sensation, assert the same direction of motion is considerable. To be more approximate, the direction which they assert was from a little south of west. This is nearly or perhaps quite at right angles to the direction which, from the testimony of inanimate objects, has been inferred to have predominated. This ought not to surprise us, for the two classes of testimony are not necessarily in conflict.

It may still prove true—indeed, it is almost certainly true—that in the earlier stages of the quaking the impulses were from north-northwest to south-southeast, while in the later stages they were nearly at right angles to that direction, as will subsequently appear. Without anticipating facts which are yet to be described, and knowing nothing of the nature of the impulses at their origin, we know that a wave in a solid body may and does set up vibrations of its particles, some of which are to and from the origin or coincident with the direction of propagation, while others are at right angles to that direction; the former being called normal, the latter transverse, vibrations. Moreover, it is known that both forms of vibration usually occur in great earthquakes, and that the normal ones come first and the transverse ones follow.

Thus, without going beyond the facts already recited, we might suppose that the motions in two directions, separately testified to, really occurred. But it will also appear that there were at least two distinct centra or origins, one situated N. 30° W. from Charleston, and another due west of the city, and thus impulses from the second centrum would equally explain the matter.

It is also easy to see how the directions of the early waves may have escaped attention and recognition by the senses; for when the first impulses from the northwest arrived in full vigor surprise and consternation reigned supreme. At a later period, after people had recognized the nature of the disturbance, had rushed from their houses into the open air, and had in a measure recovered their self possession, so as to be able to observe what was going on around them, only the east and west waves remained to be observed.

Thus, while the testimony of inanimate objects indicates a northerly and southerly motion as the more forcible and destructive, the testimony of individuals, from their sensations, more frequently in-

dicates an easterly and westerly one. In order to reach a conclusion on this point it is necessary to have a wider range of facts before us. The next step, therefore, will be to endeavor to extract from the testimony some general conception of the duration of the quaking, the varying phases, and the characteristics of those phases.

According to the testimony of some, the first intimation of the disturbance was a strange sound or murmur. Others say that with the sound they felt the trembling, and that both increased, at first steadily but by perceptible stages, and then suddenly or by swift degrees, to the full roar and energy of the climax.

Dr. Manigault resides in a very quiet street near the Battery, and but a few hundred feet from the estuary of the Ashley River. He was engaged in a game of chess, and a member of his family was sitting by an open window. The latter, surprised or perhaps alarmed by a strange prolonged sound, arose, crossed the room, entered the hall, and passed out into the open air before the doctor became aware of anything unusual. The sound appeared to come across the water of Ashley River from the west-southwest. Another observer of intelligence was seated in the park at the Battery, near the statue of Jasper. He suddenly became conscious of a deep murmur, which swelled in volume, and which appeared to come from the open bay, lying southeastward. Very soon there was a sound of agitation in the leaves of the trees overhead, and at the same instant, he thinks, he became aware of a tremor in the ground. Springing to his feet, there suddenly broke upon his ear a rapid swell in the sound, which became a mighty roar, and with the roar came the shock.

Dr. A. D. Lee was with a small party in a boat near James Island, a very few miles from Charleston and about a quarter of a mile from shore. He states that a rumbling noise was heard coming from the sea before any shock was felt. "The direction of the sound was from southeast to northwest. We heard it for an appreciable time before we felt any shock. In fact, every succeeding roar came from the same direction." "There was no distinct wave [of the water surface presumably is meant] but an irregular disturbance of the water."[1]

The foregoing will illustrate the drift of a considerable amount of testimony to the effect that the first indication was the sound. But there is also a larger amount of it to the effect that the sound and the tremors were felt simultaneously. It seems unnecessary here to give this testimony in detail, and it may suffice to indicate its general character. It comes in every instance either from observers who were so situated that the sound of the earthquake filling the air with its vibrations would either be confounded with other sounds

[1]C. McKinley's account of the earthquake. Charleston Year Book, 1887, pp. 336, 389.

incident to a city, or would not be heard at all in its earlier stages. Most of such observers were within houses situated on busy streets, or in rooms which the sound would not penetrate easily until it had reached a considerable degree of intensity.

Among those who distinctly recognized the sound before the shocks there is the widest discrepancy as to the directions. If we consider the statements of those who were near the water, they affirm in every instance that it was heard coming from the water. Those who were sitting in houses away from the water designate almost every point of the compass. There is a group of statements by many persons that, both at the beginning of the great catastrophe and of some of the more vigorous subsequent shocks, they were apprised of its coming by the outcries of people a few blocks away, which were heard before they felt any tremors. This, however, is asserted much more frequently of the subsequent minor shocks than of the principal one.

It has been asserted of many earthquakes that their coming was preceded by a murmur, swelling gradually into a loud roar, and culminating with the principal convulsion. At the same time so much conflicting testimony has been blended with these assertions, that it has been regarded as a doubtful feature. It may be well, therefore, to examine this matter by the light of those physical laws which have a bearing upon the question. The general theory of the motion of earthquake waves will be discussed at some length in another part of this work, but we may here anticipate enough of that discussion for present purposes.

In every great earthquake there are thousands of individual waves or tremors imparted to the earth mass. These waves have varying degrees of wave length and amplitude. All of them move with enormous velocity, which, as will hereafter be shown, is probably not far from three miles per second, or nearly fifteen times as fast as a

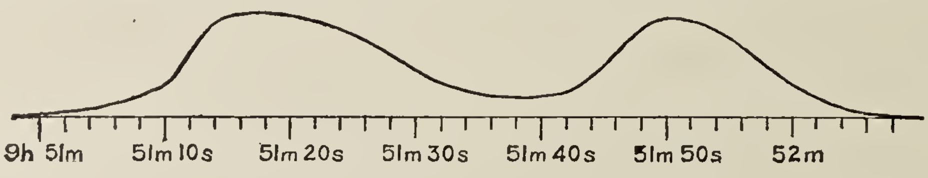


FIG. 8. Curve of intensity and duration.

sound wave in the air. As the impulses approach the surface of the ground more or less obliquely from below, they pass from the compact solid rocks into more loosely aggregated strata, and finally into the surface soil. In passing from one medium to another these waves are greatly modified, but ultimately they impart a vibratory motion to the surface of the ground and to objects resting upon it.

Owing to the great swiftness of propagation a tract of ground no larger than that occupied by the city of Charleston is completely traversed by each impulse in less than one second of time, and we


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shall make no material error by considering a tract of that size as being affected throughout its entire extent simultaneously by any single wave. A succession of waves throws the ground into a continued state of tremor. But there may be and generally is required a large number of waves to set objects vibrating in a sustained manner and with sufficient violence to manifest the strongest effects of the vibration.

Every rigid object is susceptible of vibratory motion, but considered as a mass it has some definite "period" of oscillation or natural pitch. If among the thousands of impulses to which it is subjected there is a considerable number whose periods agree with that of the particular object, the vibratory effect becomes cumulative and the amplitude of it increases with each impulse. These vibrations are in turn communicated to the air and produce sensible sound, provided the oscillations are rapid enough to affect the ear. Coming from all places within earshot at once, the sound is a murmur, filling the whole air. What the ear hears, therefore, is not the earthquake waves themselves, but the secondary vibrations imparted by those waves to stationary objects in the neighborhood.

The earthquake wave has come, it has passed, it has gone, with a swiftness which the observer can no more appreciate than he can the time of passage of a flash of lightning. Hundreds, and perhaps thousands, of them have passed in the same way. Their coming and going are never heard at all, strictly speaking, but only the secondary effects upon fixed objects. If, now, the first impulses sent out by an earthquake consist of small waves which repeat themselves for a perceptible time before the great impulses begin, it is quite intelligible that they may cause sounds which will be perceived before any sensible quaking is recognized.

A somewhat interesting consideration here suggests itself. It may be after all that the failure to feel the trembling on the part of any observer is to be attributed not to the feebleness of the tremors nor even to the dullness of those sensations which would apprise us of them, but to the fact that, when the ear catches a strange and unusual sound the attention is so engaged in listening that it is wholly diverted from the other sensations, which would have been very noticeable if the ear had perceived nothing. Thus if two persons had been in the same situation but one of them stone deaf, would not the latter have felt the tremors as soon as the other heard the sound?

It appears from the testimony that the beginning of the earthquake consisted of light tremors, which were recognized first by the murmuring sound. These gradually increased in loudness, and then the trembling of ground and buildings became perceptible. This trembling continued to increase until, somewhat suddenly, the violent oscillations came and the earthquake was at its height. The duration

of this preliminary phase can be estimated only from the descriptions which various reporters have given of what they did.

Purely subjective estimates founded upon recollections of mental processes only are not to be trusted. These are usually much too brief. A single statement like that of Dr. Manigault is far more conclusive. His son, sitting by the window, heard the sounds, was startled by them, arose and walked across the room into the hall and out of the house before the doctor was aware of anything unusual. The sound could have been produced only by the light preliminary tremors. To become aware of the strange sounds and to perform the subsequent actions before the arrival of the destructive phase must have required a considerable number of seconds, probably not less than ten and not necessarily more than fifteen. From Mr. F. R. Fisher's testimony a similar estimate may be made. The statement of Mr. Marshall also indicates for the preliminary sounds and tremors an interval not less than ten seconds and probably not more than fifteen. The testimony which would indicate a briefer period comes wholly from persons who were so situated that the first sounds would not readily be heard by them. The consensus, however, is general that this phase occupied a considerable number of seconds; most probably about twelve seconds.

The second phase was the most destructive one. It came suddenly, and while people were wondering what was the cause and meaning of the sounds and vibrations they heard and felt. There is little that can be said beyond what has already been stated as to its special characteristics. All was confusion and dismay, and no man was sufficiently calm and self-possessed to make observation. The duration of this phase it is difficult to estimate. Here, also, subjective estimates are worthless.

There is, however, almost universal agreement that there were two maxima of intensity. The first maximum has already been designated as the second phase. This was followed after an unknown interval by a considerable relaxation of the vigor of the shocks constituting the third phase. Then the quaking increased (fourth phase) until it reached an intensity which was probably less than that of the first maximum. This passed gradually into the final or fifth phase, in which the tremors died out rather rapidly into quietude.

Although there are no means of estimating accurately the several durations of the second, third, and fourth phases; i. e., the two maxima, with the intervening minimum, a rough approximation may be made to the united durations of the three. The estimate must rest not upon what people thought, but upon what they did. During a visit to Charleston a gentleman (who desires that his name shall not be mentioned) recited to me in great detail a series of acts which were repeated as nearly as they could be recalled and timed. They represented by definite association the beginning of the first maximum

and the intervening phases to the end of the second. Five trials gave a duration of fifty seconds.

Probably a similar estimate would be made from the account given by Mr. Thomas H. Tolson, of Baltimore, who was visiting the city at the time and was a guest at the Charleston Hotel. His account is so circumstantial and so intelligent, that I give it in full:

> I had been sitting outdoors, opposite the hotel, talking with an old gentleman, and about 9.45 bade him good-night, went over to the hotel and soon went to my room, which was on the third floor from the ground. When I lit my gas, an extension burner which you pull down, I heard a noise and supposed I had broken something. I made an inspection, but could find nothing broken. Then I went to place my hat on a bureau, and just then the shock came, without any warning. I would have fallen if I had not thrown my hands out and clung to the window. It seemed as though the hotel was lifted up and swung backward and forward a distance of fifteen or twenty inches at each vibration. I was terrified. At the very first shock the lights in the house all went out, and I was in perfect darkness. Then the plastering began to fall. It flashed through my mind that I should endeavor to get out of the house, and I got out into the corridor and groped my way, in utter darkness, amid falling plaster. Other people in the house were likewise groping their way out. When I reached the ground floor I could see a little from the reflection from the street lights. The air was filled with plaster dust. All around was a terrible roaring and moaning sound, and the din was heightened by the falling of timbers. I found the front door of the house closed, a fortunate thing for me, as it saved my life. It took me a moment to find the knob, and as I was looking for it tons of brick fell down from the upper part of the house in front of the door. If I had found the door open I would have been buried under the bricks. I ran out through the heaps of fallen bricks and fell twice in getting to the middle of the street. There I remained terror-stricken.

The Charleston Hotel is a very large building; its corridors are long; its stairway circuitous. It seems as if a single minute were a short allowance of time for all the actions and movements described by Mr. Tolson.

Another correspondent (who subsequently repeated and timed his actions) states that when the first violent shock came he sprang from his bed, seized a child from its cradle, descended two flights of stairs, slowly picking his way in the darkness traversed a long hallway, went out of the door and reached his garden, narrowly escaping death from a falling cornice as he emerged from the door. The ground rocked violently for several seconds after he reached it, but soon became quiet. The estimated duration was between forty-five and fifty-five seconds.

Other accounts are less detailed, but most of them indicate a duration of about the same length, or at least are not inconsistent with it. Those who depend solely upon their sense of duration independently of their actions almost invariably give a shorter, often a much shorter, period. A considerable number, recalling their actions and making an off-hand estimate of the time required to perform them, estimate the duration of the violent parts of the earthquake, including the intervening minimum, to have been about forty-five seconds.

We may, then, estimate with a fair degree of approximation that the total duration of the earthquake in Charleston was about as follows:

| | Seconds. |
|---|---|
| First phase of preliminary sounds and tremors | 12 |
| Second, third, and fourth phases | 50 |
| Fifth phase of vanishing tremors | 8 |
| Total | 70 |

We have still to inquire whether the movements gave indications of well-marked vertical components. The answer is in the affirmative, though such components were not often manifested conspicuously. Perhaps the most striking instance is to be found in the report of Mr. A. de Caradeuc, chief engineer of the South Carolina Railway. In the yard of this railroad, on Shepard street, is a large shed for the protection of the passenger coaches, the roof of which is upheld by posts 12 feet apart. Each post rests upon a brick pier, sunk into the ground and capped by a cast-iron cap, in the center of which is a hole one and three-fourths inches in diameter and six inches deep. An iron dowel pin let into the foot of the post enters this hole to the depth of six inches. In several instances the posts had been lifted sufficiently to draw the dowels entirely out of the holes and leave the pins resting upon the iron caps.

This has been supposed by many to indicate that the shed had been projected upward with force sufficient to lift portions from the ground; an explanation which is not only improbable but uncalled for. The tower of St. Michael's Church, as described by Dr. Manigault, was found to have settled into the ground nearly a foot, and the floor within the tower was bulged up considerably. This, too, has been supposed to have resulted from repeated upward blows of great violence. The real explanation of these phenomena, I conceive, will be found in those surface waves which were set in motion by the earthquake in which one component of motion is vertical.

Many persons have testified that they both felt and saw the floors of their rooms heave and tilt and felt themselves raised and lowered as the waves passed under them. These statements are borne out by the following incidents:

Some of the houses have beneath them shallow cisterns holding a supply of rain water, and during the earthquake the water was tilted out of them and poured over the adjoining ground.

Very many persons have asserted that they saw waves moving along the surface of the ground and resembling in form and motion the waves of the sea. As the phenomenon is a remarkable one, though asserted in almost every great earthquake, it seems proper to give some of this testimony in detail. Mr. McKinley, in his narrative, gives the statements of Captain Jervey, who was favorably situated for observing the phenomenon.[1]

[1] Charleston Year Book, 1886–'87.

On Tuesday night, August 31, Captain Jervey was at his home, sitting upon the piazza of his house, when the great shock occurred. The floor of the piazza is about twelve feet above the ground. The house fronts towards the south and a street lamp was brightly burning directly across the way and lighting up a considerable space around it.

Captain Jervey distinctly heard the roar of the earthquake coming from the northwest, and "heard also the cries of the frightened people at a distance in that direction before feeling the slightest motion." The sound, when first noticed, resembled that of a squall at sea, and was thought for a moment to indicate the approach of a tornado. Immediately afterward the tremor of the building began to be felt, and, as it increased with the increasing sound, Captain Jervey at once understood its character, and called to his wife not to rise from her bed, "as that was the safest place."

He had risen from his seat before the tremor reached his position, and having turned in that direction, plainly saw the northwest corner of the house first rising as the disturbance increased. As the wave passed under it, the southeast corner was lifted in turn, and after that "the house was kept in a regular rocking motion, like an old flatboat in a chop sea." This motion continued through about half the period of the disturbance, and was immediately succeeded by a lateral shaking motion along an east and west line, which was suddenly communicated to the house before its rocking motion ceased, and was as violent as the vertical motion itself. The progress of the waves as they passed the house, going towards the southeast, was plainly observed, although they traveled with incomparable swiftness. The shadow of each moving ridge cast from the gas light was distinctly seen.[1] The waves were not in long rollers, but had rather the appearance of "ground swells" in deep water. The apparent height of these swells, from the level of the trough to the level of the crest, was "not less than two feet;" the rise of the corners of the house in the first instance corresponding with this estimate. The subsequent continued motions of the building necessarily rendered further comparisons of level impracticable.

Some very important testimony as to the height and direction of the earth waves on the night of August 31 is given by Dr. F. L. Parker, a prominent physician of Charleston, who was on Tradd street, between Greenhill and Logan streets, when the first shock occurred. Dr. Parker says:

> I had just reached a point on Tradd street opposite Mr. Lewis F. Robertson's garden gate when I heard a roaring sound, apparently in the direction of James Island Cut, which was southwest of where I stood. I made up my mind that a cyclone

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[1] This statement seems to need further explanation. It may perhaps be a mistaken impression, derived from the apparent movements of shadows of other objects projected upon the moving ground.

was coming, and instinctively turned towards the direction indicated, confidently expecting to see the air filled with the flying débris from James Island. Seeing that the sky was perfectly clear, I stood awaiting developments, when I heard another and louder roar coming from the northwest. I then began to feel the vibrations of the earth very distinctly, and realized that they were produced by an earthquake. From that instant the vibrations increased rapidly and the ground began to undulate like a sea. The street was well lighted, having three gas lamps within a distance of 200 feet, and I could see the earth waves as they passed as distinctly as I have a thousand times seen the waves roll along Sullivan's Island beach. The first wave came from the southwest, and as I attempted to make my way towards my house, about one hundred yards off, I was borne irresistibly across from the south side to the north side of the street. The waves seemed then to come from both the southwest and northwest and crossed the street diagonally, intersecting each other, and lifting me up and letting me down as if I were standing on a chop sea.

I could see perfectly and made careful observations, and I estimate that the waves were at least two feet in height. In order to make my way along the street I had to tack, so to speak, from one side to the other, frequently being compelled to stop and hold on to something to keep from being thrown down. My progress along the street was similar to that of a person in a rapidly moving railway car who tries to walk from one end of the car to the other. When I had reached a point in front of Dr. Fraser's residence I saw the high brick wall between his house and the house of Mr. Parker Ravenel reeling from west to east, and am sure that it leaned over at times as much as forty to forty-five degrees from the perpendicular. At this moment one of the chimneys of the house on the opposite side of the street came crashing down in front of me. The greatest violence of the shock was over before I reached my house.

Mr. A. M. Lee, who resides just opposite the point where Dr. Parker first heard the roar, states that he also distinctly heard the first roar come from the southwest, and a moment or two later heard another and louder roar coming apparently from the northwest.

The following extracts from notes made by him soon after the shock of August 31 have been kindly supplied by Mr. J. K. Blackman, of Charleston:

I furnish with pleasure, at your request, the following notes of some striking incidents which came under my observation at the time of the great earthquake of August 31 and on the following afternoon. I have been very careful in the statement of facts, and have confined myself to particulars which I can personally vouch for.

At the time of the shock I was standing in an upper room of my house, a frame dwelling, at 5 Logan street. The night being oppressively warm and close, all the windows and doors of the house were wide open. Everything without was as still as death. The first intimation I had of the shock was the shaking of the mirror on a bureau which stood against the south wall of the room. I next felt the quick vertical movement of the house, and am satisfied that it was at least five or six seconds before I heard the roar and felt the house begin to rock violently—from northwest to southeast. I observed at the time, and also during subsequent shocks, that this rocking, swaying motion struck the northwest corner of the house first, and always succeeded the vertical vibration by a few seconds, the interval varying with the violence of the disturbance. After the first few seconds it was impossible to fix accurately the direction of the swaying motion. The house is 65 feet long, running due east and west, and as the wave seemed to strike the building on the western end, at an angle diverging to the north, a wrenching motion was produced,

which caused the building to oscillate both northeast and southwest, as well as to assume a rotary motion, the resultant of the other two and conflicting motions. I had neither the means nor the inclination to make exact observations during the progress of the great shock, but from notes recorded the next day and during the week ensuing, when every incident was painfully impressed upon my mind, I have selected the following memoranda:

I made some effort during the night to observe, if possible, the movement of the earth waves; but, as each successive shock came, I found my attention engaged by other matters, and it was not until 5 o'clock the next afternoon that I accomplished my object. The shock at 5 o'clock Wednesday afternoon was probably the most severe of those that succeeded the great shock during the month of September. I was standing at the corner of Tradd and Legaré streets when I heard the preliminary roar, and determined to make the desired observation at all hazards. Tradd street is paved with Belgian blocks, and when the movement of the earth began I was standing in the center of the roadway. After the first vertical tremor had passed, and while I was being swayed to and fro by the succeeding horizontal movement, I distinctly saw four or five separate waves pass across Tradd street from the northeast to the southwest. As nearly as I can estimate the width of the several waves, they were about as wide as the roadway between the sidewalks; as to their height, I would not like to venture an estimate, but each seemed to be at least a foot high, and was certainly high enough to be plainly seen. Had Tradd street been under water, and had I been standing in a boat on its surface, the motion communicated to my body by the passing swells could not have been more plainly felt, nor could the waves have been more plainly seen. The waves traveled at a very high rate of speed, and followed each other almost simultaneously [*sic*]. Although I experienced a very large number of shocks, the shock of Wednesday afternoon, September 1, was the only one during which I could distinctly see the waves of motion.

The visible waves, like those upon the surface of a body of water, if real, constitute a phenomenon for which there is no adequate theory. They are truly mysterious, and the scientific inquirer has no liking for a mystery. In every great earthquake events have been described which amaze and perplex us until we recall how utterly unreliable are the statements of people indescribing what they saw and felt amid the terrible excitement and consternation of an event so appalling; and then the impulse is to dismiss them as optical illusions or mental delusions on the part of the witness. But the assertion that there were visible surface undulations somehow refuses to stay dismissed, and comes back after nearly every great earthquake like a ghost to haunt us. The evidence in support of their reality is vast, cumulative, concordant, and free from the suspicion of collusion. The witnesses are men whose "reputations for truth and veracity stand high in the neighborhoods where they reside." We must deal with this testimony just as we would with that attesting any other strange phenomenon. Assertions which agree with our common experiences we accept readily as soon as we are satisfied of the character and capacity of the witness. But the assertion of a strange thing is compelled to bear a heavy burden of proof. It seems to me that in the present case we must admit the general testimony that true gravity waves, wholly distinct from the elastic

waves which constitute the true earthquake shocks, traverse the surface of the earth in some localities, and under conditions of the soil and surface strata which are favorable to their propagation. This kind of wave is peculiar to liquids, and is inconsistent with a medium possessing a high degree of rigidity. But if the medium be a viscous one, then their possibility is admissible; still, however, subject to restrictions depending upon the degree of viscosity. When it approaches the solid condition, a wave, even if it could be started, would very quickly—almost instantly—die out through the absorption and transformation of its motion into the work of overcoming molecular friction. In proportion as the viscosity approaches the liquid condition, in that proportion is maintenance of the motion of a gravity wave possible. As Charleston and the country round about are underlain by numerous beds of highly mobile quicksand, and no consolidated rocks are near the surface, it is conceivable that the viscosity approaches much nearer to liquidity than to rigidity, and thus a limited extent of propagation of gravity waves near the surface might be accounted for. The difficulty of accounting for the origin of such waves is much greater.

If we admit the occurrence of such waves, we may find in them the explanation of numerous phenomena. They would explain the vertical movements, the large amount of swaying in some buildings, and especially the opening of cracks in ground through which water and sand were outpoured. They would explain the spouting of wells which was reported in many places. They would also explain those manifold phenomena which indicate that the surface soil has been subjected to a great amount of distortion—pulling, twisting, and squeezing.

It may be of interest in this connection to refer to the accounts of the New Madrid earthquake of 1811–'12, where those who experienced its greatest violence in the epicentral tract with one accord speak of the immense visible waves which were seen to roll swiftly along the surface of the ground, opening in wide cracks upon the crests, which shut together in the troughs, the trees swaying at large angles and interlocking their boughs as these waves passed under them.

One of the most interesting but most difficult questions in every great earthquake relates to the amplitude of motion. This quantity has never been measured except either in quakes of small energy or in localities remote from the center of disturbance. In those localities where the energy is of a highly destructive degree no instrumental results have ever been obtained, and it is probable that the amplitudes in such cases often exceed the capacity of the standard seismographs to record them. This will be discussed more at length in a subsequent part of this work. Direct indications of the amplitude of motion at Charleston are not numerous. Two facts have already been cited which seem difficult to account for without the


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assumption of an amplitude of nearly or quite a foot. One is the well of the great gasholder at the city gas works, where a circular wall of masonry 128 feet in diameter displaced the retaining earth eight inches on one side and two inches on the opposite side. The other is the warehouse of the South Carolina Railway, which was bodily displaced eight feet nine inches. The latter displacement must necessarily be regarded as the cumulative effect of a number of impulses, but it seems as though each impulse must have had a very considerable amplitude; how much it is impossible to say. With regard to the displaced gasholder, it is very difficult to understand how the amplitude could have been less than the total displacement of the retaining earth, however numerous the individual waves may have been, and the occurrence appears to demand an amplitude even greater than this displacement.

On the other hand, so great an amplitude may be a merely local manifestation, exceeding greatly the average for the city. How great that average may be there is no means of knowing. In a subsequent chapter considerations will be brought forward in favor of the view that a mean amplitude of three or four inches is not an excessive estimate.

# CHAPTER III.

## THE EPICENTRAL TRACTS.

The village of Summerville lies 22 miles northwest of Charleston, on the South Carolina Railway. It contains about two thousand people, many of whom have their daily occupations in Charleston. About 8 o'clock on the morning of August 27, 1886, the people of this village were startled by what seemed to be an explosion. Some thought a heavy cannon or blast of gunpowder had been fired. Others imagined the explosion of a locomotive or the boiler of some of the phosphate works on the banks of neighboring rivers. The sound and the shock, which were sudden and simultaneous, conveyed to every one an idea of nearness of the originating cause. But no cause was visible. There were no cannon and there was no gunpowder used for blasting in the neighborhood; and the phosphate works were several miles away; yet the sound seemed very near.


Fig. 9. Wrecked house at Summerville.

Those within their houses ran out, expecting to find the cause of the disturbance in their door yards; those already without looked before and behind, to right and to left, expecting to find the explanation a little way off. The sound was loud, sudden, and startling. The

shock was a single jolt or heavy jar. In a moment all was quiet. Neighbor questioned neighbor, but only to have his question tossed back. Some one suggested an earthquake. They had read of them, but nothing they had read of seemed to correspond to the phenomenon just experienced. It was the talk of the day and evening, and people went to bed thinking that the morning papers would bring an account of some occurrence which would fully explain the mystery.

FIG. 10. A wrecked dwelling.

Near 5 o'clock on the morning of the 28th the people were aroused by a repetition of the occurrence with more vigor than before. Sleepers were abruptly wakened, and those awake were startled and alarmed. This time opinion took more definite shape. Those who were skeptical before were inclined to believe it was an earthquake. This belief gathered strength during the day and grew into conviction upon the day following through the occurrence of light tremors, some accompanied by sounds, others passing in silence. During the 30th and during the daytime of the 31st all was quiet, and the manifestations seemed to have ceased entirely. The Charleston papers had published reports of them, but had treated them with levity. These reports were telegraphed over the country, but the accounts of them were of so unusual and perplexing a character, that they gave only the impression that some trifling commonplace event had been transformed by fertile imaginations into an earthquake. In Charleston nothing uncommon had been noticed, though afterwards some people averred that they had felt a slight jar or tremor at about the same time as the first preliminary shock at Summerville.

On the evening of August 31 came the catastrophe. It broke upon the village not as a *crescendo*, but in full force. At the first impulse, before people had time to realize what was happening, they were tossed from side to side, or flung to the ground, from which they could not rise. For a few moments it was impossible to stand or walk. Most of the people were within doors. First one corner or side of the house was violently raised or knocked up, then another corner or side. The structure seemed to dance up and down from the effects of rapid and powerful blows beneath it. The floors and ceilings were warped and twisted; the timbers groaned and crackled; the chimneys, crushed at their bases, sank downward, carrying fire-places, mantels, and hearthstones through the floors to the ground below. Several declared that it seemed as if the houses were galloping madly down-hill. Among the many well written accounts of these events at Summerville the following may be selected as an example. It was written by Mr. Thomas Turner, president of the Charleston Gas Light Company.

I arrived home from my business in town about 7 p. m. on the 31st of August, and having dined, I spent a very pleasant evening with my family up to 9.30 p. m., when I left the house, the members of my family retiring to their rooms. The evening had been unusually sultry, but clear, and beautifully starlight. I had been out in the garden admiring the beauty of the evening and was entering the door of the hall of my house, when, without any rumble or warning, the floor seemed to sink under me. I seized the door jambs to steady myself, when the floor seemed to go down in front of me at an angle of twenty-five or thirty degrees. It was so sudden and unexpected, that I was thrown forward into the hall about ten feet and as quickly thrown backwards, and before I could fall upon the piazza I was again thrown forward into the house. At this moment I observed my sister-in-law crawling on all fours, she having been thrown from the door of her chamber, which she was just entering, into the middle of the sitting room. Amidst the rolling and rocking of the building she managed to reach the hall, but was unable to regain her feet. At this moment we observed the upper part of a lamp, which had been jerked off its stand, to fall upon the floor and burst. The oil took fire, and amidst the roaring and violent motion of the house, we succeeded in extinguishing it with pieces of carpet and rugs. Immediately after we received another shock, which threw us from side to side of the hall. Having gotten the members of my family together, and supporting my niece, who was in a fainting condition, we endeavored to leave the house amidst the crash of falling chimneys and plaster; but at every attempt to reach the door we were hurled backward and forward and from side to side, as if we had been in the gangway of a steamer in a heavy cross sea. After some delay we reached the garden. I then returned to get wraps and chairs for the ladies and again experienced severe shocks and rumblings. These were repeated at intervals of several minutes during the night, but were not of so violent a nature, although the earth waves were very perceptible and several times upset a small lantern placed on the ground.

On examining the house we found that the hearths and fireplaces had been shaken out and had gone down under the building, carrying fenders and fireirons with them. The two chimneys had been overthrown—one to the southwest, the other to the northeast. The house had been moved, and the piles on which it rested careened over thirteen inches in a northeasterly direction. The main chimney seemed to have crumbled at its base, the main body of it sliding down and driving

the mantels into the middle of the floor. As we considered the house too dangerous to occupy, my family camped in the garden for several nights.

The night of August 31–September 1 was passed by the people of Summerville in the open air. The blacks, overcome with terror and bewildered by a power so vast, so mysterious, and so strange, gave themselves up to prayers and wailings, which alone would have rendered the night hideous enough; the white people, deeply awed and impressed, met the terrors of the darkness with the fortitude which they had so signally proven on former occasions. The great shock was followed in the course of eight or ten minutes by another of great power, but inferior in force to the first. Throughout the night many minor ones were felt. The peculiar characteristic of all of them was the deep, solemn, powerful boom, like the report of a heavy cannon, usually accompanied by a quick, short jar. Sometimes it was prolonged into a heavy roar or rumble, as if many reports were delivered in a volley. The number of these was never recorded.

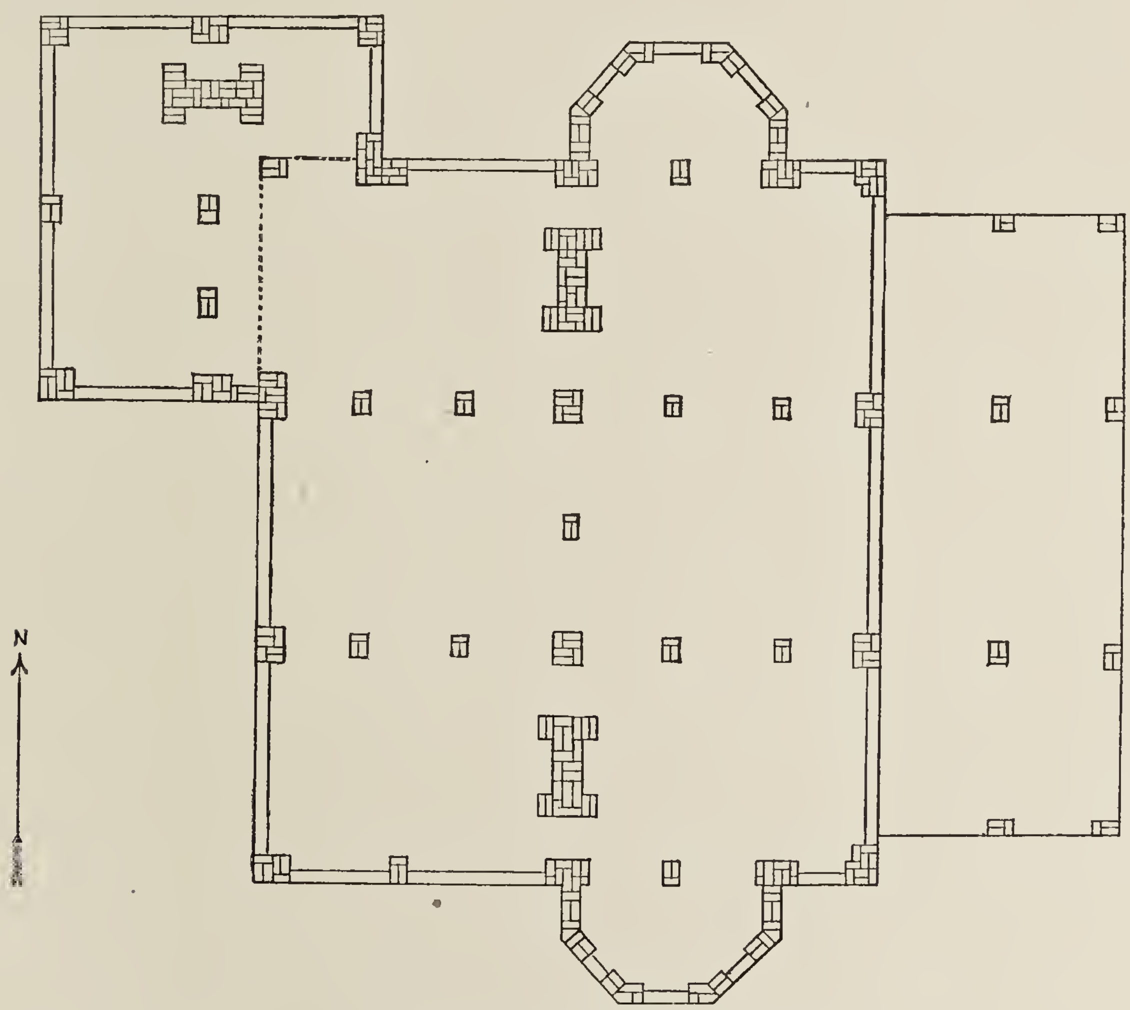



FIG. 11. Plan of the Hastie House, at Summerville.

When daylight came and an examination of the houses was made the damage was found to be great. The houses here are all built of wood, and stand either upon posts driven into the ground or upon

brick piers, which raise the first floor of the house from 4 to 6 feet above the soil. It seems as if such a construction, subject to a powerful earthquake, in which any considerable horizontal motion of the ground might occur, would trip the under-pinning at the first lateral impulse and allow the structure to fall bodily. In a few cases it did so. Eight houses suffered in this way and were badly wrecked. But the great majority of them, though moved upon their supporting piers, did not fall. The energy of the earthquake was expended in effects of another kind; for the direction of its impulses was nearer the vertical than the horizontal. The brick piers were found to be more or less disintegrated, as if pounded; while the wooden ones were driven deeper into the soil, as if they had been hammered by a pile-driver. Many of them were inclined, though still supporting the houses. An illustration of the structure of these buildings with their supporting piers and of the effects of the earthquake upon them is given by Mr. McGee (Figs. 11–15). The injuries to chimneys were also very characteristic. The portions projecting above the roofs were generally dislodged and thrown to the earth; sometimes they were hurled to considerable distances; but in many cases, instead of being snapped off clean by a horizontal fracture, were broken along a highly inclined plane, as if sheared, and fell easily to the ground. There was a marked tendency to fall in a northwestern and southeastern direction, but instances could be found of chimneys falling in almost any direction. The most striking effects, however, were upon the main bodies of the chimneys below the roofs. All of them showed signs of severe usage, and a very large number of them were crushed at their bases; the bricks as well as the mortar being disintegrated and shattered, allowing the whole column to sink down, carrying fire-places, mantels, and hearthstones with it through the floors. All this indicates a direction of motion more nearly vertical than horizontal. Yet the effects of horizontal motion were by no means small.

Mr. W J McGee, of the Geological Survey, who visited Summerville on September 3 and 4, says in his notes:

Perhaps three-fourths of the chimneys in the town have been displaced, and perhaps three-fourths of these have been thrown either to the north or south. Fissures were common and extensive and considerable streams of water flowed from them. In some fields in the vicinity of Summerville one-quarter of the surface has been flooded by water and is covered by films of yellow or blue sand; and in some cases long lines of little hillocks of sand brought up from the fissures, extending in various directions, dot the fields from side to side at intervals of 15 or 20 yards. It was immediately observed on reaching Summerville that the direction of destructive motion was vertical rather than horizontal; that the chimneys seldom appeared to have been thrown, but to have been simply crushed and then to have toppled over. Examples will be noted further on. The Episcopal church, in the southwestern part of the town, a wooden structure 30 by 50 feet, resting on thirty-six brick piers, each two and a half feet square and four feet high, fronting N. 70° E., has been displaced northward two and a half inches at the west end and one and three-quarters inches

in the middle and one inch at the east end. This northward displacement of the church has not carried with it any of the nine pillars under the south wall, but one or two of the pillars under the north wall and several of those beneath the church have partaken of its movement. Several of the pillars, however, exhibit crushing at their summits, and a few have oblique fissures through them, extending from the south obliquely downward to the north. The crushing is more pronounced in the pillars beneath the four corners, and is nil in many of them beneath the floor and under the front of the light wooden portico.

The houses in Summerville are of wood, and supported on pillars either of wood or brick, five to seven feet in height; the chimneys being generally independently supported by arches or piers built up from the ground. The main building is commonly surrounded, partially or wholly, by a piazza supported on columns like those beneath the house, but usually more slender. This description applies to Colonel Gregg's house, the injuries to which will be fully described, as they may be regarded as representative of what happened to many others. The building has piazzas on the west, south, and east, and a shed-roof or lean-to on the north. The pillars of the main building and piazza are of brick, but those under the lean-to are round logs 10 to 12 inches in diameter. Two large chimneys in the main building are independent. The whole building has been displaced one or two inches to the northward. The west end has moved on the piers, while the east end has carried the piers with it, and they are now inclined two inches from the vertical. All of the piers under the heavier portions of the house, and particularly the corner-posts, are crushed at their summits, driven perceptibly into the ground and fissured obliquely, and several of them have fallen. The piers beneath the piazza and some of those beneath the floor are but slightly injured, and at the time of examination supported the weight of the house. The portions of both chimneys which projected above the roof were thrown northward and both crashed through the roof of the shed and one of them through its floor, a section of the chimney four feet long standing upright but in reversed attitude on the ground beneath the house. The projecting part of the other chimney was completely shattered. The basal portion of one of the chimneys is crushed, intersected by oblique cracks, and is spread laterally five or six inches. The basal portion of the other is completely crushed, and the entire chimney from one foot above the ground to the level of the roof has collapsed into a conical heap of loose bricks about the base. The wooden pillars supporting the lean-to are of sound pine, and were set into the earth to a depth of two or three feet. The condition of the earth about the bottoms of these posts indicates that they have been swung in all directions, compressing the earth on all sides, and finally returning approximately to their original positions, leaving an annular space between the post and the compressed earth of perhaps an inch in width. Some of the smaller brick piers, which extend several inches below the ground, appear to have swung with the main building in like manner, forming open crevices between the brick and earth on all sides. Some of them appear to have been driven into the earth with such force as to produce a depression of the surface for six inches or a foot in all directions from them, with occasional curved concentric fissures.

Mr. McGee also describes the injuries to the residence of Mr. W. S. Hastie, located near the center of the village:

It is shown in plan in Fig. 11 and in perspective in Fig. 12. The entire building was displaced northward two inches. In general the more slender piers have gone over with the building, though the sills are sometimes displaced upon them. The structure has been displaced on the heavier piers and the southeast and northwest corner piers have been seriously crushed. Both of the bay windows are torn from the building below, and the piers supporting the walls at the junction of the bay windows with the main building are crushed and split from top to bottom, as shown

in Fig. 13. The north bay window has been thrust northward and the south one southward. Several of the slender piers, 8 by 12 inches, supporting the floor of the house have been driven into the ground, as represented by the plan, Fig. 14 and section Fig. 15, illustrating the depression of the surface of the ground beneath the pier A, supporting the sill opposite the southern bay window. The piers supporting the piazza are but little injured, but all those under the heavier parts of the house are literally crushed, as if they had been subjected to the action of a pile-driver. Except in the uppermost layer of bricks the crushing is usually confined to the mortar, which is of inferior quality ; but in the uppermost layer the bricks themselves are frequently broken and partially pulverized, and the overlying sills are pounded and splintered. The chimneys rising from the roof of the main part of the house are apparently uninjured save by the loss of a few bricks, but the kitchen chimney has been thrown northward, striking the ground at a point 12 feet from the foundation wall; the roof here being 16 feet high. The chimneys in the main building were supported on independent piers built up from the ground. These are so crushed and fissured as to have spread five or six inches at a point three feet above the ground as imperfectly shown in Fig. 13.

One or two hundred yards south of the depot at Summerville stand two old chimneys originally attached to a wooden house which had been destroyed by fire. One of these fronts north, the other west. They appear to stand very insecurely. The brick is of ordinary quality, the mortar appears to be inferior, and both bricks and mortar were injured by the fire which destroyed the building. The one facing west leans two or three inches to the westward and the other leans still farther. It seems as if one might push either over with one hand. From testimony of residents the altitude of these chimneys was not perceptibly changed by the earthquake. Both of the chimneys are now crushed, cracked, and fissured in all directions, as shown in Fig. 16. The top of the one in the foreground has been displaced southward one inch along an oblique fracture and a lower segment has been similarly displaced northward two inches. The upper portion of the other has been thrown northward and a lower section partially dislodged, yet there has been no other displacement. Why these chimneys have not fallen is one of the many mysteries of the great earthquake.

For several weeks following the principal disturbance minor shocks continued to be felt at frequent intervals. Many of them would have been considered very forcible and alarming had they not been greatly disparaged by the convulsion of August 31. Almost all of them were accompanied by loud detonations. Mr. McGee thus describes several which he experienced.

I reached Summerville about 5 o'clock p. m. Detonations were heard at intervals averaging perhaps half an hour. From that time until 9.30 p. m. occasional and very slight spasmodic tremors of an instant's duration accompanied the detonation. I endeavored to determine the direction from which the sounds came, but no two individuals agreed. They seemed to me to come from the northwest. They were much like, but somewhat more muffled than peals of thunder at a distance of half a mile or more, or perhaps more like the discharge of a blast in a mine or quarry at a little distance. It was my impression that the sound was sometimes about as grave as the ear can perceive, resembling somewhat the tremulous roar sometimes accompanying combustion in locomotives.

Mr. McGee also describes more powerful shocks which occurred during that night, and which consisted of rapid vertical vibrations, accompanied by the usual roar, as if from a rapid succession of detonations.

Although a roaring sound is the almost invariable accompaniment of an earthquake shock exceeding a very moderate degree of vigor, the sounds at Summerville appear to have been highly exceptional and perhaps unprecedented. They were heard throughout the entire epicentral tract, though it is difficult to determine whether they were

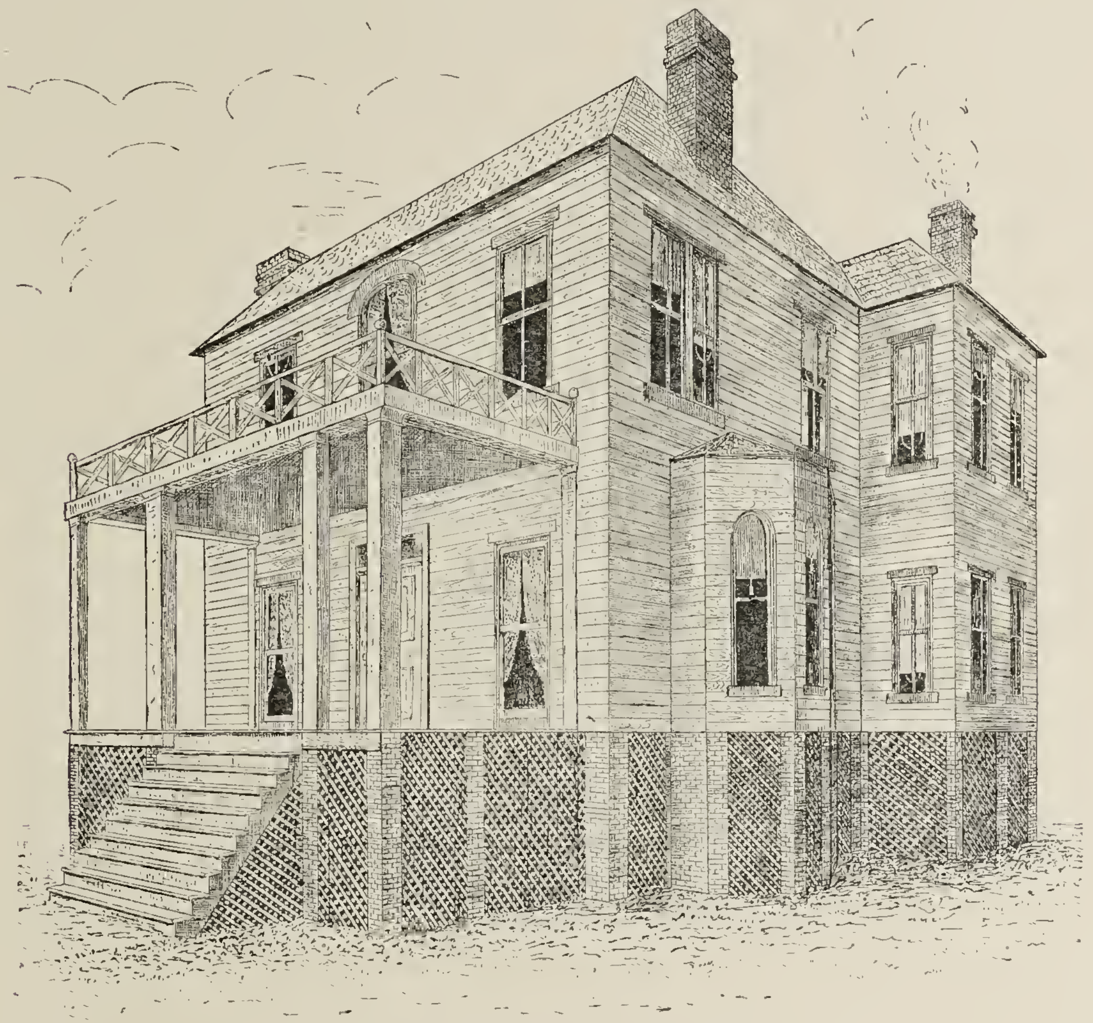


FIG. 12. The Hastie House (perspective).

as loud and frequent in other parts of that tract as at Summerville. In this village there was a much larger number of intelligent witnesses to testify to the facts than elsewhere, and it is hardly possible to make a comparison between localities which furnish evidence differing so much in amount and degree of definiteness. But the testimony is clear that at Summerville the sounds were very loud and of an explosive character. They continued with diminishing frequency through the remainder of the year and even up to July 1, 1887.

Lincolnville is a small village, situated between two and three miles southeast of Summerville. It contains a few hundred inhabitants, nearly all of them negroes. It has several well-built wooden cottages, and a larger number of cabins, the dwellings of the poorest class of blacks. The violence of the shocks here was apparently a little greater than at Summerville, though the difference is so small

that its existence may seem doubtful. A larger proportion of the buildings were wrecked, and in some instances the destruction was more thorough. The damages were for the most part of similar nature to those in Summerville, and indicated vertical movements of great power. A number of buildings were moved to a considerable distance. One house which was wrecked was supported on wooden posts, some of which were broken off, others forced down laterally, while several retained their positions. The house moved ten feet south and three and a half feet east. The upper part of its chimney was little injured, but the lower part was crushed into a pile of ruins. Two or three hundred yards northeast of this house another cottage was thrown five feet south and three feet east. Its chimney was collapsed in the same manner as the first one. On the other hand, many cabins and some cottages escaped serious injury, but they all showed that they had been subjected to violent vertical movement and also to horizontal swaying. The piles on which they rested were hammered into the ground and the inclosing earth at their lower ends was molded so as to leave annular spaces around them.

Summerville and Lincolnville are the only villages within the epicentral tract. The buildings which occur elsewhere within its limits are isolated, and though the aggregate number of these isolated structures is considerable, they are scattered thinly over a large area and are also irregularly distributed. There were, however, two groups of indications which were most instructive and which greatly supplemented this somewhat defective testimony. These were, first, the cracks and craterlets rent in the soil, from which large quantities of water and sand were poured forth; and, second, injuries wrought upon the railways which traverse the epicentral tract in different directions. As these vestiges of the earthquake are of heterogeneous character and as one group of facts is but loosely comparable with another, some difficulty arises as to the order and methods in which they may be most instructively presented and discussed. The following course has been decided upon, viz: To point out, first, where the epicentral tract, or rather tracts—for there are two of them—are situated; second, to give a brief account of the craterlets; and, third, to discuss the facts as a whole in such manner as shall display clearly the variations of intensity along lines radiating from the epicentral points of the two tracts. This method is possibly open to the objection that it inverts the logical order which is more commonly pursued in scientific reasoning. It first states the conclusion and then the premises. This method is a dangerous one, liable to lead to bias and special pleading. But while admitting the force of the objection, no other course has suggested itself which does not offer objections still more serious, and the logical dangers in the present instance are imaginary rather than real. The advantages of this method are, that

as the facts are stated their bearing upon some definite proposition becomes obvious, and they are seen in relation to each other. This gives them interest and coherence which would otherwise be wanting.

A careful examination of the ground leaves no doubt that there were two tracts, both of which disclose clearly the epicentral characters. The larger and more important one is a nearly circular area,

FIG. 13. The Hastie House, showing piers after earthquake.

whose center is near the little station named Woodstock, on the South Carolina Railway, about sixteen miles N. 30° W. of Charleston. The smaller tract is situated almost due west of Charleston at a distance of 13 miles. Both these distances are measured from the intersection of Broad and Meeting streets in Charleston, but as an uncertainty of half a mile exists in regard to the exact locations of the epicentral points, the distances given are not intended to be precise. The interval between the two epicentra is between thirteen and fourteen miles. The position of the smaller or southern epicentrum is approximately three miles west of the bridge by which the Charleston and Savannah Railway crosses Rantowle's Creek and about a mile north of the railroad.

In deciding upon the limits of the epicentral tracts it must be remarked in the first place that the limits must be arbitrary. It is well known that in all great earthquakes there is a comparatively small area around the epicentrum where the effects are most forcible and destructive, and where the movements of the ground differ in some important respects from the movements in areas more distant. The features which characterize the epicentral shocks, however, are not separated by a hard and fast boundary from those of surrounding regions. As we proceed along any line radiating from the epicentrum we find not only a diminishing violence, but a gradual change of character. At first these changes are but slight, and generally so much so as to be imperceptible. But at length the change becomes more rapid as the distance from the epicentrum increases, until we reach a point where the decline of intensity and the change of character become quite rapid for a short space. Still further on the decline continues, but at a diminishing rate. To make this more clear we may resort to a graphic illustration.

If EX, Fig. 17, represent a horizontal line upon the surface of the earth and E be the epicentrum; and if a series of vertical lines or "ordinates" be drawn from a series of points along EX, each vertical line having an altitude proportional to the intensity at the point at which it is erected; and if the summits of these ordinates be connected by a curved line, the curve thus obtained will show a tendency to conform to that which is represented in the diagram. The properties of this type-curve are as follows: Since the intensity at the epicentrum is greater than elsewhere, the ordinate EA will be greater than any other. At a little distance from E the intensity will differ but little; but as the distance from E increases the intensity declines more and more rapidly. The rate at which the intensity declines at any point is represented by the inclination or steepness of the curve vertically above that point. For a time this inclination increases as we depart from E and the curve grows steeper and steeper. There is, however, a point at which the steepness attains a maximum. Beyond that point the steepness becomes less and less. When the distance from E becomes very great the inclination of the curve becomes very slight; i. e. the curve becomes nearly horizontal.

It is obvious that there is no point of the curve at which any abrupt change either of intensity or of character occurs. If, therefore, we are to distinguish any epicentral tract apart from any other we must do so arbitrarily. Some distinction is convenient and even necessary for purposes of discussion. It has been decided, therefore, to include in the epicentral tract of the principal focus (whose epicenter is near Woodstock) a circular area 20 miles in diameter, and in the southern tract an elliptical area whose axes are 9 and 6 miles respectively.

Throughout a great part of those areas which will here be considered as the epicentral tracts, and in considerable areas outside of them,

the ground was broken by many fissures, through which water was extravasated. In many places the fissures were abundant, but did not discharge water. Indeed, the fissuring of the ground within certain limits may be stated to have been universal, while the extravasation of water was confined to certain belts. The area within which these fissures may be said to have been a conspicuous and an almost universal phenomenon may be roughly estimated at nearly 600 square

FIG. 14. Piers driven into the earth.

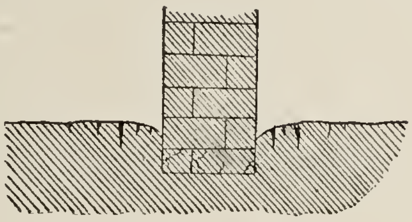



FIG. 15. Second view of pier.

miles. They occurred also in vast numbers outside of this and over a much greater area, but with less continuity and less frequency. Perhaps the best idea of their general distribution and the limits within which they were very abundant may be gathered from Mr. Sloan's delineations upon the map (Pl. XXVIII). The fissures seldom attained a width of more than an inch, excepting in the vicinity of river banks, where an actual movement of the banks towards the channel of the river opened exceptionally wide cracks parallel to the river side. Elsewhere the widths of the fissures were seldom so great as one inch. But where water was extravasated in large quantity, some point in the line of the fissure would be often enlarged by the rapid flow or outrush of the water into a round hole of considerable size, with a crater-basin at the ground surface. These craterlets were of all dimensions, from the most diminutive up to 20 feet or more in diameter.

As a general rule the water brought up great quantities of sand and silt. Some of these sands were nearly pure quartz and white; some with a reddish tinge, some yellowish or gray; others were largely mixed with dark clay and of an iron-gray color. Most interesting of all were sands consisting almost wholly of small plates of mica (muscovite) or quartz grains mixed with flakes of mica. It seems little doubtful that all these sands were brought down by the rivers from the granitic areas in the northwestern part of the State and redistributed in the ancient estuaries and "littorals" which have at a very recent epoch become dry land. Buried quicksands beneath the surface soil in this vicinity have long been known. In some places the beds are known to lie but a few feet deep. The quantity of water discharged during the earthquake was so great, that every stream-bed, even though ordinarily dry in summer, was awash. It was asserted by many of the residents in some parts of the epicentral

tract that the waters were spouted upwards to great heights, giving at first the impression and current report that the waters were hot. It is certain that the temperature of the waters was in every case normal. That here and there it was thrown up in jets to a height

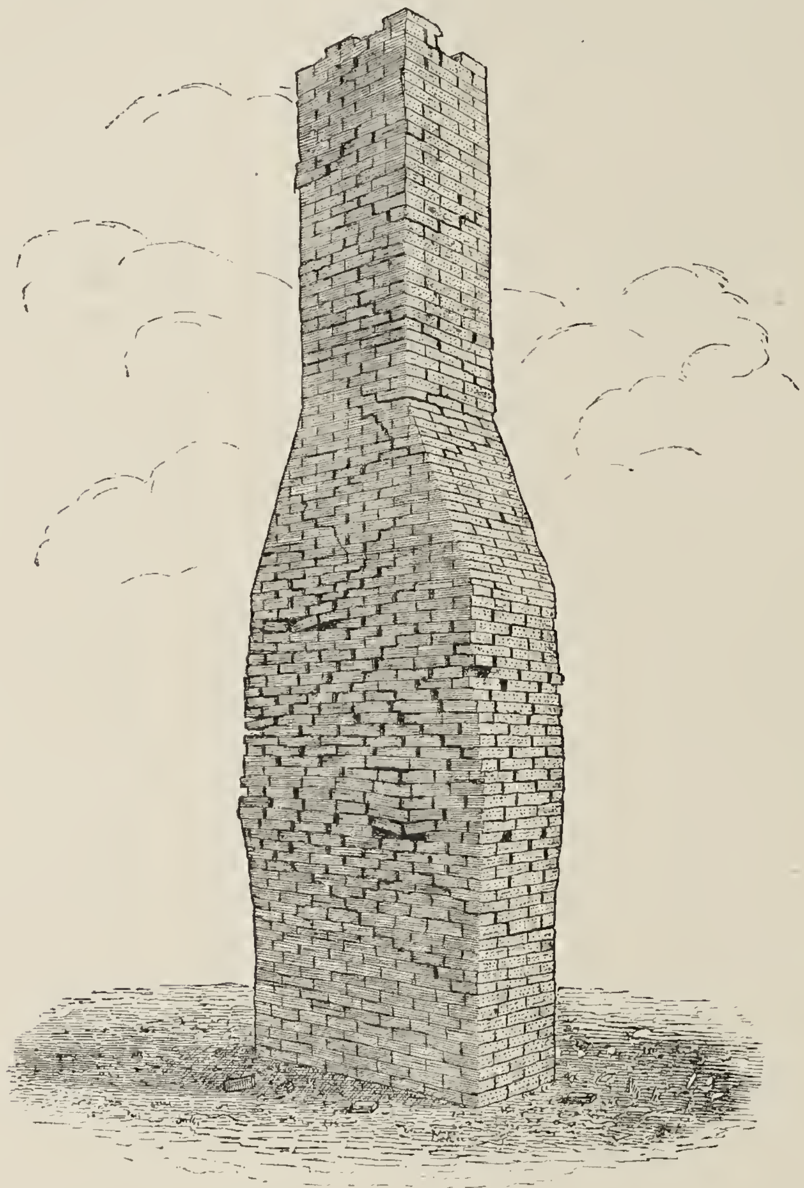


FIG. 16. Spreading of chimney.

of fifteen or twenty feet is rendered probable by finding the sand and mud smirching the limbs and foliage of trees overhanging the orifices. But it is equally probable that such projections were exceptional and confined to a few localities. As the earthquake occurred after the full darkness of night had fallen, the testimony of observers on this point must rest upon some other evidence than mere vision in order to receive much credence.

By far the best indications of the variations of intensity throughout the epicentral tracts are furnished by the railways which traverse them. There are two railways, the South Carolina and the North-eastern, which traverse the northern epicentral tract, while the south-

ern tract is crossed by the Charleston and Savannah Railway. As the South Carolina Railway crosses the northern tract almost centrally, we will begin by noting the action of the earthquake upon its road-bed and superstructure in detail, as set forth in the very careful series of observations made by Mr. Earle Sloan immediately after the catastrophe.

Leaving the railway station at Charleston, no marked disturbance of the track or road-bed was disclosed for a distance of 3⅝ miles. Occasional cracks in the ground and in the ditches alongside were seen, from which sand and water had been extruded in abundance. Some traces of violence of a character insufficient to call for any repairs were perceptible in places. At the point referred to rails were notably bent from their proper places and the track had suffered a longitudinal displacement, by which the joints between rails were opened. Thence to near the 5-mile point no marked disturbance was found beyond the occurrence of cracks and small sand-craters. At the 5-mile point the track again showed signs of great stress, the fish-plates being torn from their fastenings by the shearing of the bolts, and the joints between rails being opened seven inches in both tracks. Near the 6-mile point the joints were again found to be opened and the road-bed was permanently depressed six inches. Thenceforward the signs of increasing energy became more and more decided.

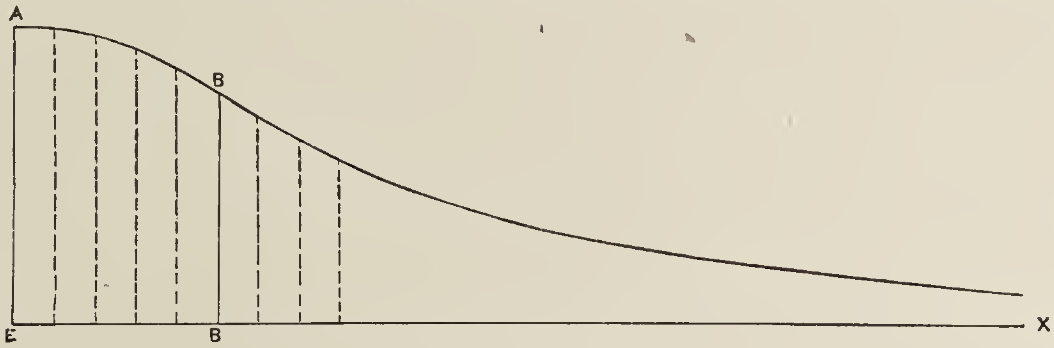



FIG. 17. Intensity curve.

Small deflections of the track from its original alignment became frequent, as did also depressions and elevations of the road-bed. Near the 9-mile post the changes of intensity seemed to proceed with the greatest rapidity. The lateral displacements of the track were not only more frequent, but greater in amount. A few hundred feet beyond the 9-mile post was a serious flexure in the track. It was here that an outgoing train from Charleston met with a disaster. (Pl. XIX.) The fireman, while leaning out of the cab, was thrown to the ground by the sudden lurch of the first great shock and seriously injured. As the train moved onward it came to the sharp kink in the track where it was derailed and wrecked. It was in this vicinity also that the craterlets showed a great and rapidly increasing development. Not only were they very numerous, but

they increased in size as the station at Ten-mile Hill was approached. In a large "borrow-pit" beside the road the ground was honeycombed with them, and the amount of sand which had outflowed was very great.

These craterlets seemed to reach their greatest development, both in size and number, near Ten-mile Hill. Some of them were very large, one measuring 21 feet across. (Pl. XX.) Many acres of ground were overflowed with the sand, which was two feet or more in thickness near the orifices, thinning out towards the margins. These craterlets, however, depend for their size and number not alone upon the violence of the earthquake, but also upon the nature of the strata beneath. The water and sand thrown out came from a few feet only beneath the surface, and were originally contained in beds of quicksand thoroughly saturated with water. The earthquake opens a crack in the ground above, affording free communication with the surface. The overlying soil being of much greater specific gravity than the water, the latter rises by virtue of the simple hydrostatic law, bringing the loose fine sand with it. Attempts to sink artesian wells at Ten-mile Hill have been defeated by a bed of watery quicksand about twelve feet below the surface, which could not be kept open. The area thus underlaid by quicksand is very large, but it is not universally distributed over the entire epicentral tract. Wherever it occurs near the surface the craterlets are abundant; but they are frequently absent or very scarce where the energy of the earthquake is known from other indications to have been very great.

The distortions of the track and its dislocations appeared to have nearly attained their maximum between the 10-mile and 11-mile posts. It was often displaced laterally and sometimes alternately depressed and elevated. Occasionally severe lateral flexures of double curvature and of great amount were exhibited. Many hundreds of yards of track had been shoved bodily to the southeastward. The buckling always took place when this lateral shoving encountered a rigid obstacle, usually a long rigid trestle. At the northwestern end of the trestle the accumulation of rails resulted in a sharp kink. Corresponding extensions of the track by the opening of the joints and shearing of the fish-plate bolts occurred some distance to the northwestward. It has been suggested by many that this longitudinal thrusting of the track was a simple down-hill movement. This was not the case. On the Charleston side of the epicentrum the shove is always toward Charleston; on the opposite side of the epicentrum it is in the opposite direction. In both cases the track has been shoved away from the centrum, and this holds good whether the grade is up or down.

At Ten-mile Hill there was a severe distortion, a large amount of accumulated rail being jammed against the "frog" where the branch

DISASTER ON THE RAILROAD.

road leading to Lamb's leaves the main track. Three-quarters of a mile farther on was another severe flexure, the track having been driven longitudinally to the southeastward, so as to form a double or S-shaped curve by the accumulation of rail. Near the 11-mile post, on the other hand, the track was parted longitudinally, leaving gaps of 7 inches between the ends of the rails. Here also was a considerable depression or sink in the road-bed, amounting to 18 inches

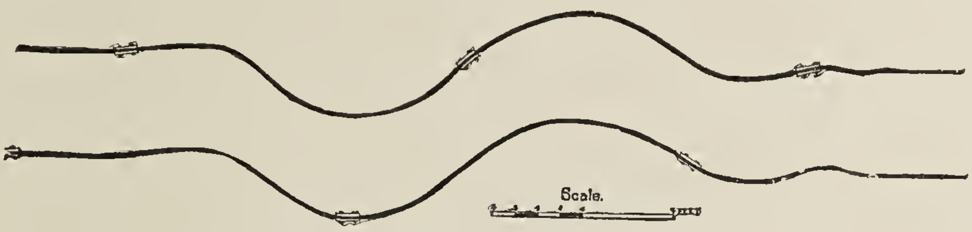


FIG. 18. Flexures in the railway track.

through a length of about sixty feet. Half a mile farther on there was another stretching of the track, opening the joints as much as 7 inches. Throughout this part of the track, from Ten-mile Hill nearly to the 15-mile post, there were many lateral deflections of the rails, generally with long chords. There were also numerous sudden and

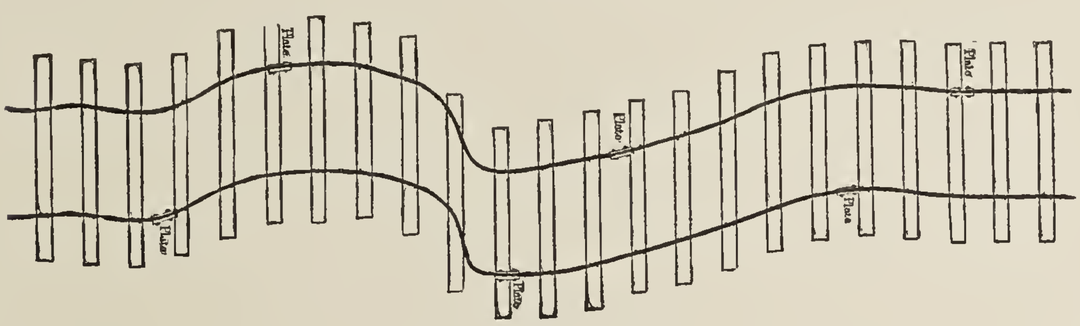


FIG. 19. Another flexure.

short depressions of the road-bed. These lateral deflections are presumed to be due to that violent wriggling and twisting of the ground—the "vorticose" movements—which almost invariably occur in the epicentral tracts of great earthquakes.

The epicentrum is inferred to be situated opposite the 15½ or 16 mile point of the railroad and at a distance of about 1 mile from it. Around this spot there was little to indicate either the degree of violence or the characteristics of the motion. The nearest structures were the railroad and a few wooden sheds with brick chimneys at a place named Woodstock, and these were completely collapsed, with every indication of powerful vertical motion. Through a distance of more than four miles from the 11½-mile point the railroad failed to disclose any of those sharp kinks indicative of a sliding of the track; but it revealed traces of violent movement nevertheless. Many earth-molds were formed by the ties as the ground vibrated horizontally beneath the rails, and the alignment was distorted by long

flexures with small ordinates, showing that many of the vibrations had been in directions perpendicular to the course of the track and of sufficient amplitude to produce a permanent distortion of the ground. Elevations and depressions, some of considerable amount, were also produced. This section of the road, however, lies partly through a swamp and partly through a rice-field, and the ground is little suited to preserve traces of violence. Being also of a less rigid nature, it would be less likely to inflict the more severe injuries upon the road-bed.

At the little station called Ladson's the road rises upon higher and firmer ground. In the few houses at this spot Mr. Sloan found traces of intense vertical shocks. The chimneys were collapsed, and the wooden structures were severely shaken and strained in a northerly direction. A little beyond the railroad track was flexed sharply with a double curvature. At the 18½-mile point was another severe flexure, a single rail 29 feet long on each track being bent into an **S**, one branch being 12½ inches, the other branch 16 inches from the original straight line. At the 19¾-mile point a still more complex flexure was found. Beneath it was a culvert, which had been strained towards the northwest and broken as in Fig. 20. About five hundred feet farther on was the "kink" represented in Fig. 18. The northwestern end of this flexure ran upon a short wooden trestle, at the south end of which the maximum flexure represented in Fig. 18 occurred. The length of this trestle is only 14 feet and its height about twelve feet. At each end heavy planking is spiked across the vertical supports, in order to make a bulkhead or retaining wall for the abutting ends of the railway embankment. The earth in the embankment had been molded or pressed away from the bulkhead 6 inches at the northern end and 5 inches at the southern end of the trestle. I can only interpret this as meaning an amplitude of vibration in the line of the track of at least eleven inches.

In the vicinity of the 20-mile post there is a long stretch of roadbed and track which was distorted by many sinuous flexures, generally of no great amount. Here the road traverses a swampy tract. A little beyond the 21-mile point it crosses another swampy place, this time by a long trestle, which was distorted both laterally and vertically for a considerable distance. Thence onward to Summerville (21⅝ miles) were numerous flexures, one of which was a sharp **S**-shaped curve. A little beyond the station at Summerville was a broken culvert, and the track immediately over it showed a sharp double curvature.

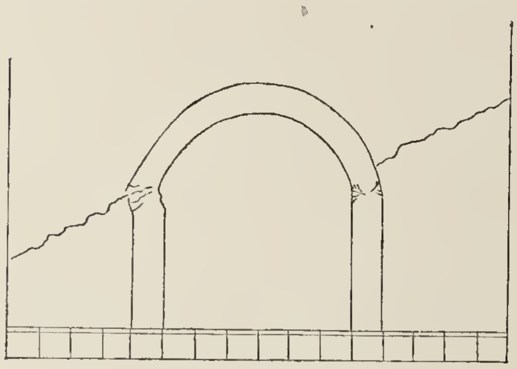


Fig. 20. Broken culvert.

From this point onward the disturbance to the track and road-bed diminished rapidly, and until Jedburgh was reached (nearly six miles beyond Summerville), none of the more violent distortions of the rails were observed. The intervening space, however, showed considerable longitudinal stress in the earth-molds pushed up by the ties in the thrusting motion of the superstructure. At Jedburgh ($27\frac{1}{2}$ miles) there was a severe buckling of the track, as shown in Fig. 19. It occurred at the south end of a long heavy trestle.

Let us now review briefly these disturbances presented by the South Carolina Railway in order to ascertain what they signify concerning the origin of the forces which produced them. In Fig. 21 the horizontal line represents in vertical projection the track of this road from the 7-mile to the 25-mile post. Midway between, at or near the 16-mile post, a vertical line is drawn, which we will suppose to extend indefinitely downwards into the earth. On either side of the 16-mile point the road exhibited a symmetrical series of phenomena, with their respective directions (or "orientation") reversed. In

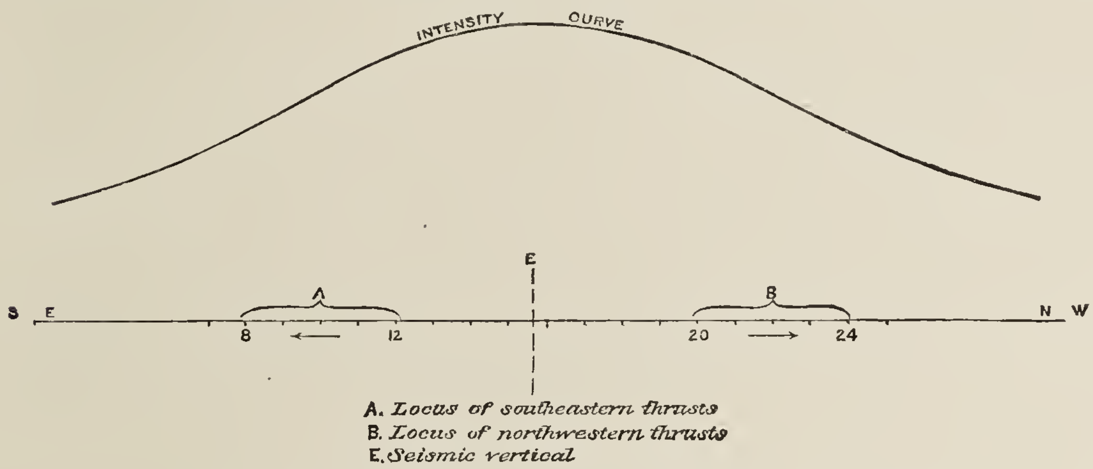



FIG. 21. Opposite directions of thrusts on opposite sides of the epicentrum.

proceeding from Charleston as far as the 6-mile point we may discern an increase of energy, but not a very rapid one. The increment, however, became more and more rapid, so that in passing from the 8-mile to the 12-mile point the change of intensity is seen to have been very great. It was within these 4 miles that the powerful longitudinal thrusts and sharp bucklings of the track with corresponding partings of the joints were found. *The greatest rate of change in the intensity south of the epicenter occurred near the 9-mile point, and probably not so much as a mile distant from it in either direction.*

On the other side of the 16-mile point we find a symmetrical group of facts. Reversing the directions, and proceeding from the 24-mile to the 20-mile point, we find a similar marked increase of intensity; and within a section of a little more than 4 miles we find a repetition of those longitudinal thrusts and bucklings with corresponding part-

ings of the joints. *The greatest rate of change north of the epicenter occurred near the 23-mile point.*

Between the two sections of extreme buckling there was an interval of about eight miles where only a few instances of it occurred. In this interval, however, the ground is for the most part swampy and soft, and probably of a nature too yielding to inflict such excessive damages, even if the forces involved were of the degree and kind which would in a firmer soil produce them.

The disturbances argue the action of both normal and transverse waves. At or very near the epicentrum all horizontal movement must be attributed to transverse waves alone and all vertical movement to normal waves alone. There was motion both horizontal and vertical and therefore both kinds of waves must have acted.

The first impulse is to attribute the longitudinal motion of the railroad track to the normal waves. But this is by no means certain. The transverse waves near the epicentrum and in localities where the angle of emergence was large, might have produced similar results; but their power to produce horizontal motion in lines radiating from the epicentrum would rapidly diminish as the angle of emergence decreased. These sharp bucklings, however, seem to have been exceptional occurrences and of rather limited frequency, while smaller lateral distortions of the track were much more numerous. When they occurred, they indicated a powerful impulse away from the epicentrum, and an impulse of exceptional severity. The best explanation that offers itself seems to be that they were produced by normal waves combined with transverse ones, producing exceptionally great amplitudes in particular spots. The smaller lateral deflections, which involve no buckling but merely a lateral distortion, can be attributed only to the transverse waves.

The symmetry of the two sets of distortions indicates that the epicentrum must lie between them. But they do not indicate necessarily whether it is near the track or at some notable distance from it. They imply, however, that it can not be very distant from it; but to determine its position more definitely, and to procure other data essential for reaching a conclusion as to the approximate depth of the focus, we must traverse the epicentral tract along another line. This shall be the track of the Northeastern Railroad.

This road lies parallel with the South Carolina Railway for nearly 6 miles from Charleston and usually but a few yards distant from it. Thence it diverges from it at a very slight angle. At about 12 miles from Charleston it curves steadily and rather rapidly to a due north direction, which it maintains for 12 miles more. In noting the various occurrences along this road it will be well to have the map before the eyes. It is to be observed that the distances on this road are numbered from the Charleston terminus, which is about three-fourths of a mile farther to the southeastward than the

terminus of the South Carolina Railway, and this difference must be kept in view in making comparisons of points which are designated by their distances from the origins of the two roads.

In the first mile and a half the road crosses an extensive marsh by alternate embankments and trusses, none of which disclosed any appreciable displacements. At the end of this distance there occurred a lateral flexure having a chord of nearly three thousand feet and an ordinate of 18 inches—a large tract of soft ground appearing to have moved bodily. At the distance of four miles the road makes a slight curve which exhibits a notable distortion. Near the 6-mile point there is a section of track and road-bed about four hundred feet long which had been depressed, the sinkage attaining a maximum of 22 inches. The first indication of marked longitudinal movement of the track occurred at about six and one-third miles, where the rails of both tracks had sheared the bolts of the fish-plates and opened the joints 14 inches. Mr. Sloan does not note any corresponding accumulation of rail in the vicinity. At the 7-mile point there is a depression within a short space over a culvert, from which point the grade ascends in both directions; and a hundred feet beyond there is a slight sinuous flexure appearing to indicate longitudinal compression, and another similar one about two hundred and fifty yards southeast of the 8-mile point.

From this point onward the indications of great intensity rapidly increased. At 8 miles 4,500 feet an embankment 16 feet high on both sides of a narrow water-way was depressed 10 inches with indication of forcible vertical motion. Some telegraph poles here were broken and thrown to the right—others inclined. At 8 miles 5,100 feet the whole superstructure was shifted four inches to the eastward. At nine miles there was long lateral flexure, shifting four inches eastward. At 9 miles 1,000 feet a six-foot excavation, embracing a broad borrow-pit, showed many craterlets, from which sand had been extravasated in great quantity. As an indication of the force with which the water and sand were ejected, the branches of trees over these craterlets were found to be covered with the sand at a height of 13 feet above the ground. Much conflicting testimony has been given as to whether the water was projected forcibly from the vents or flowed out quietly. The difficulty of seeing what actually happened in the darkness of the night is the probable cause of the discordant accounts received. The present instance, however, is conclusive that here, at least, the water was thrown out in jets to a notable height and with considerable force.

At $9\frac{1}{2}$ miles the fish-plates were broken and the rails parted $8\frac{1}{2}$ inches. Three hundred feet farther the frog at a siding was sheared and shifted 8 inches to the south. At 9 miles 4,000 feet the superstructure was deflected to the eastward. At 10 miles 350 feet was a most forcible displacement. An embankment 15 feet high was

pushed 4 feet 6 inches to the eastward along a chord of 150 feet, and a "kink" was formed in one pair of rails with a chord of 7 feet and an ordinate of 11 inches. At 10 miles 1,000 feet the wing wall of a culvert was broken and the embankment on both sides of it depressed. Throughout this part of the track all of the culverts indicated powerful vertical components. One of the best indices of vertical action was found at 11 miles 2,000 feet, where a trestle 40 feet long was supported on four "bents," as in Fig. 22. The girders above were notched two inches deep on their lower faces to receive the tops of the bents. The shock lifted the girders far enough to release the bents from their notches, and two of them fell prostrate, one to the north, the other to the south.

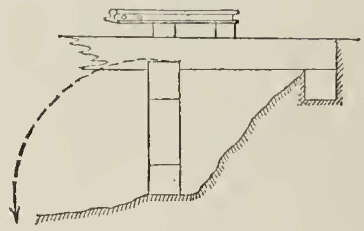


FIG. 22. Overturned bents.

At the 12-mile point there was another great disturbance. The road here enters a shallow cut. Several fish-plates were broken and the joints parted; a long flexure began, which increased for 450 feet. The road-bed and cut were here crossed by cracks of unusual width coursing N. 40° E., developing into a series or network of cracks through a belt 150 feet wide and at least 700 feet long. The widest cracks were 21 inches in width. At 12 miles 750 feet a long trestle occurs, and the superstructure upon the embankment at the beginning of the trestle was shifted 8 feet 4 inches to the westward, and also against the south end of the trestle. The ground beneath the trestle appeared also to have been shoved northerly or the trestle southerly, so that the bents were inclined, and those near the extremity of the trestle fell to the ground. It was found necessary to cut out 22 inches of the girders before the alignment could be restored.

At 12 miles 2,800 feet a culvert was collapsed, with every indication of powerful vertical action. Near by there stood a cabin, with adobe chimneys, which were also completely crushed, with the same indications of vertical force. Similar adobe chimneys, crushed in the same manner, occurred near the 13-mile point. At Otranto, 13½ miles, stood a large brick building used as a club-house by gentlemen of Charleston when hunting in the neighborhood. It was substantially built and in good repair. The earthquake demolished it. The west gable was completely destroyed and the underlying wall severely cracked; the east wall was destroyed, collapsing to the east; the piazza on the south and west fell to the ground; the north wing was parted from the building and inclined to the north; the west chimney was thrown to the northward and the east chimney forced in the same direction. (Fig. 23.)

A mile farther on, but at a considerable distance east of the railroad, are the ruins of St. James's church. This was a heavy-walled

building, substantially constructed. Though not completely prostrated, it was practically destroyed, the walls being much disinte-



FIG. 23. Club-house at Otranto.

grated rather by the vertical action than by the horizontal. Both the east and west gables were thrown to the ground, the side walls severely cracked, the northwest corner much shattered, and some of the interior pillars hammered into the ground. (Fig. 24.)

At the 15½-mile point the road crosses Goose Creek, where the south end of the trestle is deflected to the east and the north end to the west. From this point the road ascends a very gentle grade leading up to a broad sandy flat. Just before reaching it, in the vicinity of the 16-mile point, there were found evidences of intense energy of a peculiar kind. The ground was thrown into ridges or permanent waves and the rails were bent in a vertical plane to conform to the fixed undulations. The ground exhibited marked indications of violence by the cracks and fissures. Mr. Sloan was of the opinion that the expressions of intensity here were unsurpassed along the road except by the great flexure at the 12-mile section.

A little farther on the road passes into the broad sandy tract referred to, and almost immediately the signs of disturbance greatly diminish. The change of intensity is so abrupt as to suggest some exceptional cause or condition. Objects which could serve as monu-

ments of the earthquake, however, become very rare. For a distance of two miles the only structures are the railroad and a cottage near the 17-mile point. The road exhibited no marked evidence of distress.

FIG. 24. St. James's Church.

The cottage lost its chimneys, the northern one having been detached from the building and thrown over to the northward, the southern chimney being snapped off at the eaves and its top thrown northward upon the house-top. The supports on which the house rested were strained out of plumb. At Mt. Holly station (18 miles) there are a few houses, but the damages were inconsiderable, the most serious being the loss of chimneys. The intensity indicated here is unnaturally small. The station is upon the sandy tract referred to. Half a mile beyond it signs of greater intensity reappeared. Here the road descends upon ground which is less sandy and more like that to the southward, on which a greater intensity was disclosed. For a distance of about 1200 feet the track was thrown into flexures, with a displacement to the eastward of about four inches. The road soon passes once more into the sandy tract, where the indications of violence again cease to be conspicuous. The last manifestation of great energy along this road was shown in the vicinity of the 21-mile point, where flexure to the eastward was shown along a distance of 900 feet with a lateral displacement of about three inches.

The falling off of the intensity beyond the 16-mile point has been spoken of as abnormal. Possibly it may be in some measure apparent rather than real, because the number of objects which could express the intensity was very small and the evidence therefore defec-

tive. But that it is in a large measure real Mr. Sloan is persuaded, and he has given great care to the study of this section. It will appear farther on, however, that this is the border of a very considerable area within the main epicentral tract where the same defect of intensity is indicated. It exhibits a rather remarkable agreement in respect to its position with the sandy barren tract already mentioned. The thickness of the surface sands probably does not much exceed 40 feet and in many places may be considerably less than that. Whether so thin a layer is capable of producing a comparatively well-marked "earthquake shadow" within the limits of an epicentral tract is extremely doubtful, though it would be rash to pronounce it to be impossible. That there is a "shadow" of some sort here, produced either by this or by some more efficient but unknown cause, is rendered practically certain by the following occurrences. If we follow a nearly due east course from the assumed epicentrum and cross the Northeastern Railroad at right angles and proceed as far as a point named Oaks on the map (two and a half miles east of the railroad), we shall find the extreme intensity well maintained. At Oaks a massive one-story brick building was wrecked with indications of great violence. (Fig. 25.) Its three gables were all thrown out, all its chimneys broken, and a brick stable hard by destroyed. Passing onward about two miles farther, the intensity considerably declined. At a point near by a brick building was much shattered, but was evidently less violently shaken than that at Oaks. Farther eastward the indications of energy grew less, and the rate of decline along this line seemed to be quite normal and in due proportion to that observed in both directions along the South Carolina Railway.

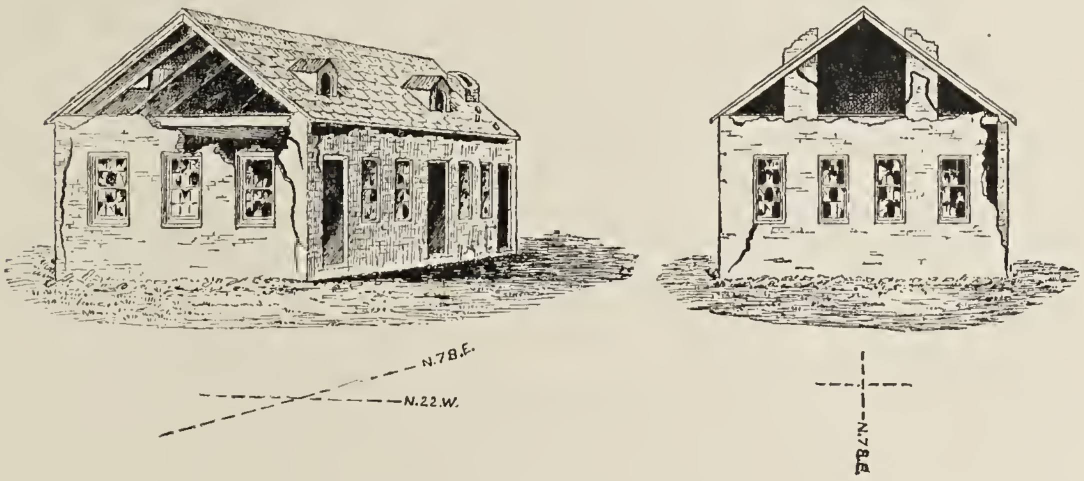



FIG. 25. Wrecked house at Oaks.

If, now, we take a line from the epicentrum passing more to the northeastward it will enter the sandy tract with a great falling off of the indicated intensity. Emerging from it east of the railroad signs of great intensity re-appeared. At the head of Back River a three-story brick dwelling suffered the destruction of its east and

west gables, the demolition of its south wall from the second floor to the roof, and the overthrow of its chimneys to the north. Here at least the violence was as great as it normally should be. Farther on in the same direction, near Cooper River, the violence decreased very notably, being expressed by fissuring the brick walls, overthrowing the large chimneys, and cracking the brick furnaces of the rice mills in that neighborhood, but without demolishing any substantial structures. In brief, the northeast line passes through the earthquake shadow near its margin and emerges again beyond it with an intensity which is apparently normal with respect to its distances from the epicentrum.

The Northeastern Railroad exhibits, so far as can be judged, the most rapid rates of variation in intensity near the 9-mile point, and again near the 19½-mile point. The latter point, however, is subject to great uncertainty, owing to the nature of the ground and the scarcity of structures which can serve as indices of the energy. In this connection it will be of interest to advert to the remarks of Mr. Sloan, who summarizes his observations in a way that leaves little to be desired. His remarks have a singular value, from the fact that they are made without the slightest reference to any ulterior views or consequences and contemplate nothing more than a terse summary of the facts as they were observed. He says:

Reviewing the displacements of the railroads traversing the disturbed area we note the following: The Northeastern Railroad at the 14-mile post crosses a broad depression, with valley line slightly above sea level, and ascends on both sides pronounced slopes constituting the water-shed of Goose Creek. About this locality various evidences of vertical force find expression, as in rupturing backs and wing-walls of culverts downwards, collapsing of adobe chimneys, depression of trestling, etc. Proceeding northerly, we observe indications of increased lateral disturbance of superstructure and road-bed, attaining maximum stress slightly beyond the 16-mile post, and thence decreasing with intermittent expressions, the final of which is found at the 21-mile post. Proceeding southerly, we find the north slope of the ridge near the 12-mile post violently disturbed, with expressions, near the crest, of the vertical component, which has sufficiently raised the stringers of the short trestle to admit of overturning of bents; thence the disturbance attains its maximum between the 10 and 9 mile posts, beyond which the indications are very occasional till we arrive on Charleston Neck, beyond which the tension has been so great as to have opened joints through the shearing of the track bolts, the opening at one place being 14 inches.

The South Carolina Railway affords increased evidences of disturbance as we proceed from about the 14-mile post northerly, indicating maximum stress between the 19 and 21 mile posts, where the most violent flexures of superstructures were found, which were always immediately south of and partly over some break in the road-bed, such as a trestle or culvert, or a point of weakness created by some swampy ground, but irrespective of grade. At the 14-mile post is a 30-foot trestle, 14 feet high, just south of which the superstructure is found flexured, the maximum flexure being immediately at the junction of the trestle with the embankment, and indicating a northerly stress of the entire superstructure, the rails seeming to drag those ties resisting longitudinal movement. Of such ties, we find one at every angle-plate, through the niches of which spikes restrain longitudinal move-

ment, the spikes at other ties merely resisting lateral and vertical movement. In dragging these ties earth-molds were formed seven and a half and eight inches broader than the breadth of ties; and that the strain had been in the main northerly is shown by the splitting of several cross-ties by spikes entering near the northerly edge. This accumulation of rail proceeding towards the north, upon encountering increased resistance in rigidity of short, stiff trestles, the ties of which are secured, is forced to buckle; and often in finding a sudden depression, affording thereby sudden change in nature of resistance, we again find lateral flexure over or about the point of weakness. The disturbance to superstructure finds final expression on the south side of the trestle near the 27-mile post.[1]

Near the 9-mile post, on low, swampy ground, a violent flexure occurred at or about the instant of the transit of a locomotive with attached train, which derailed the locomotive, wrecking it east of the track. The train was moving north, therefore towards the axis of disturbance.

Is it not a significant fact that every flexure contiguous to trestles or other points of rigid resistance, from the 15-mile post to the 27-mile post, was found to be at the south end of such resistances; whereas, proceeding southerly from the 15-mile post, the flexures are found at the northerly extremities of points of resistance?

The indications furnished by these two railroads suggested the position of the epicentrum, and also the dimensions and configuration of the epicentral tract. By themselves alone, however, they would not have sufficed to establish such a conclusion upon a sure foundation. It was a suggestion, and no more. It still remained to accept the location of the epicentrum as a trial hypothesis, and to test it by a careful scrutiny of the facts presented along numerous lines radiating from it, and thus determine whether the indications afforded by the railroads were borne out in full detail by all the facts at command. To put this question to the test, we will examine the evidences presented along eight lines radiating from the inferred epicentrum in directions as near 45° apart as practicable.

SEC. I.—Let us first follow a line drawn from the epicentrum northward. It leads us through a wilderness, with few objects to indicate the nature and force of the seismic action. About two and a quarter miles distant, and a little to the west of the north and south line, there is an old ruin known as the Middleton House—a name, however, which applies to several distinct places within the epicentral tract or around its borders. Here stood a large brick structure, long ago destroyed by fire, but the walls and chimneys were standing at the time of the earthquake. The shocks here were plainly vertical. The chimneys were crushed, and the brick arches supporting the steps also crushed downwards. The southwestern corner had been torn from the walls and apparently lifted up, then let fall

[1] The severe buckling at the 27-mile post (Jedburgh) must be regarded as an outlier or exceptionally and abnormally severe manifestation for the locality. The principal decline of intensity occurred just beyond the twenty-third mile post. To this I believe Mr. Sloan agrees, as does also Colonel Averill, the general superintendent, who resides at Summerville. Between the twenty-third and twenty-seventh mile the road showed no serious disturbance.

again inside the foundation walls, the corner fragment still retaining its upright position. The foundations of the smaller buildings were badly crushed and disintegrated. Northward beyond this point the earthquake has left no traces. The line passes at once into the sandy tract within two miles of the epicentrum, but whether it be that a true earthquake shadow existed here, or whether there was normal violence which has left no sign, it is impossible to say. The country is densely forest clad, and there is no human habitation or structure until a point nearly eight miles north of the epicentrum is reached, where there stands a wooden cottage, resting on brick piers eight feet high, and near by an old turpentine still. The cottage was not overthrown, but its chimney was cracked, as was also the cylindrical wall inclosing the still, but the injuries were uninstructive and unsuited for indications of intensity. Two miles to the westward, however, and eight miles distant from the epicentrum, some more decisive indications were disclosed. Several dead pines had been snapped off and overthrown, and a large log which had long rested on the ground had been rolled over from the position in which it had become embedded. A mile and a half farther west a house had been shifted from its supports and moved bodily several inches.

Mr. Sloan, after diligent search, was unable to find any conspicuous traces of the shocks immediately north of the epicentrum, and the few uncertain indications which he notes are mentioned rather to show the poverty of the evidence than to utilize them as measures of intensity. At a distance of eight miles to the northward he is of the opinion that the intensity was about normal, and that in the intermediate region the absence of marks of great violence was due in a great measure to a real defect of intensity.

Sec. II.—This is the line of the South Carolina Railway, extending from the epicentrum in a nearly northwest direction. As the facts along this line have already been discussed, nothing will be added here.

Sec. III.—The third section will be along a line extending due west from the epicentrum. Here, too, is a great scarcity of facts, but there are a few which indicate the intensity much more decisively than those observed to the northward. The ground showed numerous cracks and fissures, and Mr. Sloan was impressed with the idea that the vertical components in this direction were exceedingly powerful. At a distance of about three and a half miles a wooden house, standing upon brick piers, lost its outside chimneys under circumstances indicating more than ordinary violence. The most forcible impulses here were apparently vertical. A little to the west of this house the craterlets with extravasated sand were abundant. At a distance of 5 miles, but somewhat south of the line of section, are the ruins of a church, which was destroyed with signs of terri-


A LARGE CRATERLET.

ble violence. Beyond this point, at a distance of about a mile, the indications imply a notable decline of intensity, and at the Ashley River the violence was notably less. Although this section disclosed but few conspicuous monuments of the energy, Mr. Sloan has felt confidence in his belief that it was very great.

SEC. IV.—The next section will extend southwest from the epicentrum. At the place called Woodstock, immediately upon the railroad and not more than a mile from the epicentral point, are the old sheds and limekiln spoken of in the description of the South Carolina Railway. The sheds appeared to have been collapsed by a powerful upward stroke from beneath, crushing them down at once as if by a pile-driver. The vertical direction of the impulse could not well be more clearly manifested. Proceeding onward about a mile to the southwest, the line of section entered upon a belt of craterlets rivaling those in the vicinity of Ten-mile Hill. Concerning this locality Mr. Sloan remarks in his notes:

*Belt of craterlets bearing S. 80° W., N. 80° E.*—Along this ridge many dry cracks have occurred, as well as long cracks connecting series of craterlets. We here find wells cracked in vertical planes through the axis of the wells with azimuth N. 80° E., the cracks extending from the tops to the bottoms of the wells. The wells have been almost universally disturbed, many overflowing and subsequently subsiding, others filled with sand, others rendered muddy. We find, extending through a field for a distance of 700 feet, a fissure from eight to fourteen inches wide, connecting a series of large craterlets affording liberal quantities of sand. In certain flats these craterlets appear to have submerged the earth seven inches with water.

His notes indicate similar disturbances extending through a distance of about three miles. At a point about four and a half miles southwest of the epicentrum we come upon one of the most interesting and instructive monuments of the earthquake to be found in the whole epicentral tract. The locality is the site of an old town named Dorchester, long since abandoned and overgrown with forest. The place has interesting historic associations with colonial and revolutionary times, and has been made the scene of one of Gilmore Simms's most pleasing classic stories. In a thick wood, a few hundred yards from the Ashley River, stands the ruin of an old brick church. Around it are the fallen and moldering gravestones of the forgotten dead overgrown with brush and jungle. Of the church, all that remained at the time of the earthquake was the tower, which was 18 feet square at the base and rose to a height of nearly 40 feet. The walls of this tower on the northwest and southeast sides were 3 feet 10 inches thick, and on the other two sides about two feet thick. From its summit large blocks of brick and mortar—as much as 15 or 20 cubic feet in each block—were dislodged and hurled in four directions. One large mass struck the ground 35 feet from the base of the tower on the northeast side, and in its descent stripped branches and bark from a tree with which it came in contact. Another mass of nearly equal volume was hurled in the opposite direction from the

summit of the tower and to an equal distance. Large masses were also thrown in directions at right angles to the above, but not to such great distances. It was my privilege to view these relics under the guidance of Mr. Sloan, and after studying them carefully I could see no escape from his conclusion that the greater fragments had been actually projected to a distance of 35 feet from the base of the tower. That the blocks did not strike the ground nearer to the base and roll farther away was clearly established by most careful investigation, and the lacerated bark and branches of the tree immediately above the spot where the largest block lay was to my mind conclusive. (Pl. XXII.)

A little beyond this ruin is the Ashley River, where there still stands an old fort, built of a peculiar concrete, consisting of oyster shells embedded in a lime-mortar obtained by burning and calcining oyster shells—the same shell-lime which Dr. Manigault praises so highly. It deserves his praise, for the old fort-wall, built more than a hundred years ago, is as fresh and hard as newly cut granite. But the earthquake broke it in many places and severely cracked it, especially at the northeast corner. Hard by the fort are several wide cracks in the ground parallel to the river.

Crossing the Ashley, the traces of a marked decline of intensity begin to appear about a mile beyond. Two and a half miles from the river is a cluster of small buildings which, though much shaken, indicate a force much less intense than that displayed at the river. Altogether the intensity displayed along this section seems to surpass that which is disclosed along any other, with the possible exception of the one extending from the epicentrum through the 12-mile point of the Northeastern Railroad.

Sec. V.—The line to be next examined shall be that extending about due south from the epicentrum. It passes over a forest-clad, uninhabited tract, and for a distance of two or three miles south of the railroad traverses ground severely cracked and full of craterlets. The description given for the first three or four miles of the preceding section will apply to this. Strongly individualized and instructive traces are very few until the Ashley River is reached. Here the bank of the river is a rounded clay terrace, which was shaken southward towards the stream, opening a series of wide cracks parallel to the river, as represented in Pl. XXIII. The sliding of the bank riverward uprooted several large trees, which fell over into the the water. Almost directly opposite this point on the other side of the Ashley stands Gregg's Phosphate Works. Mr. McGee describes the effects here as follows:

At the phosphate works there is a two-story wooden house, shown in plan in Fig. 26. The foundation is of brick, with exceptionally good mortar, and is therefore unusually firm and strong. It is but little injured save at the corners, where the bricks and mortar are crushed and crumbling. The two chimneys, 25 feet


CRATERLET AT TEN-MILE HILL.

apart, were thrown in such directions that their débris are now intermingled, as shown in the figure. It will be observed that the southernmost chimney has been thrown the farther. Fig. 27 is a plan of the light railway tracks and washer at the phosphate works; Fig. 28 shows in plan the kinking of the rails at the point *a* in general plan, and Fig. 29 illustrates the settling of the embankment and shifting of the trestle-work leading to the washer. The heavily braced timber framing upon which the washer is supported is seriously strained, and it would appear that the entire building has been moved eastward two or three inches. The viaducts through which the sand and mud are carried from the washer to the waste heap have both been shifted northward two to four feet, and the trestle-work upon which they are supported has been in part thrown down. The retaining dam below the mill pond was extensively broken by longitudinal and crescentic fissures, settled a foot or more, and at one point a heavy live-oak tree growing upon it was partially overthrown to the westward.

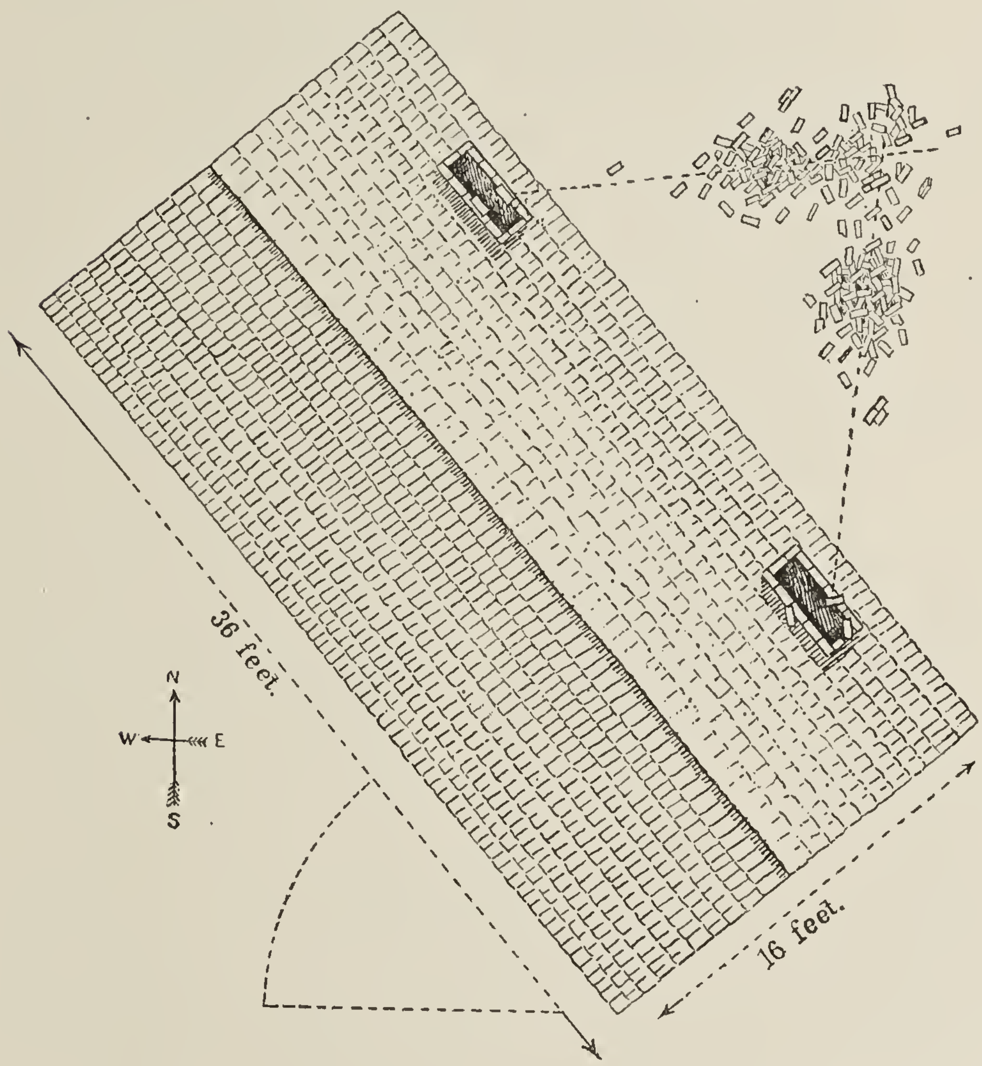



FIG. 26. Overthrown chimneys at Gregg's—seen from above.

Along the course of the Ashley River, between Dorchester and the Charleston Phosphate Works, at Lamb's, the indications of the violence of the earthquake are very numerous and impressive. To recite them in detail would be to protract the account unnecessarily,

and only a few notable occurrences will be cited in detail and the remainder will be treated more summarily. At Ebaugh's Phosphate Works, on the northeast bank of the Ashley, where the violence

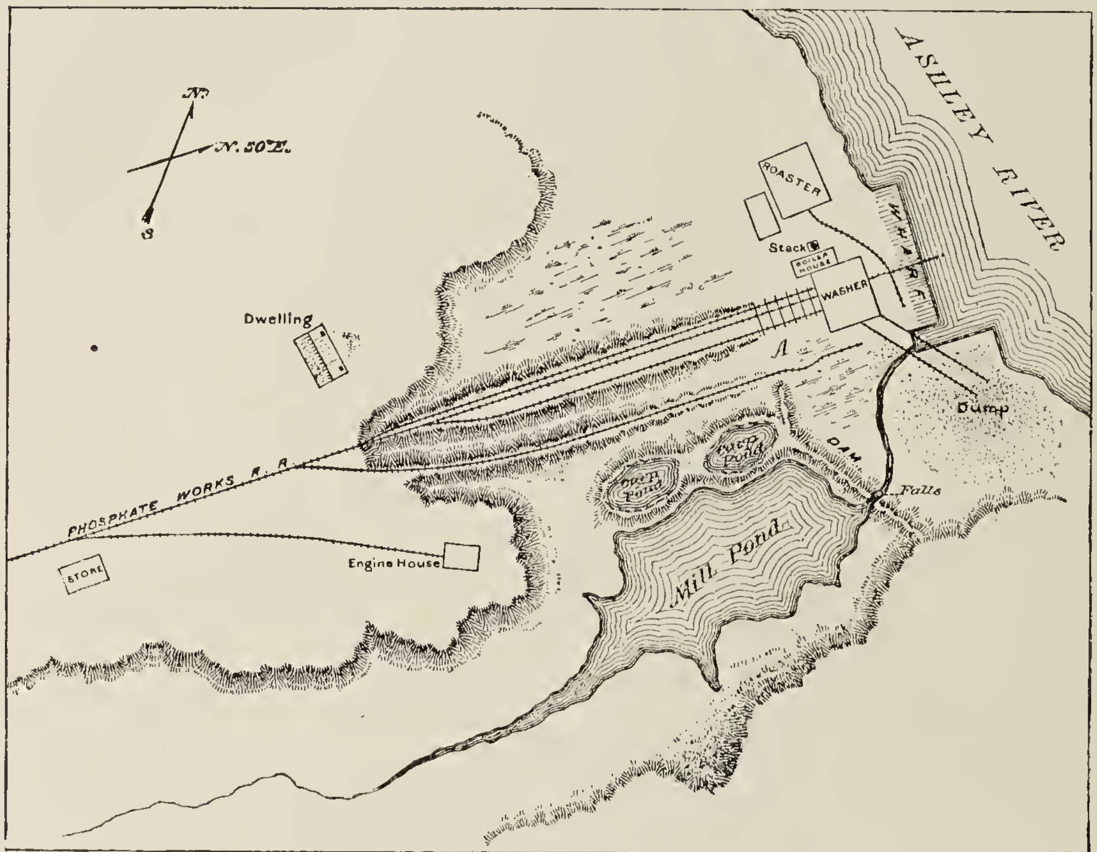



Fig. 27. Plan of track and washer at Gregg's.

indicated was very great, there was one occurrence of special interest, which seemed to show a large amplitude of motion. Some of the lead curtains in the sulphuric-acid chamber, which hung vertically, had been oscillated in the direction of their own planes, and in so

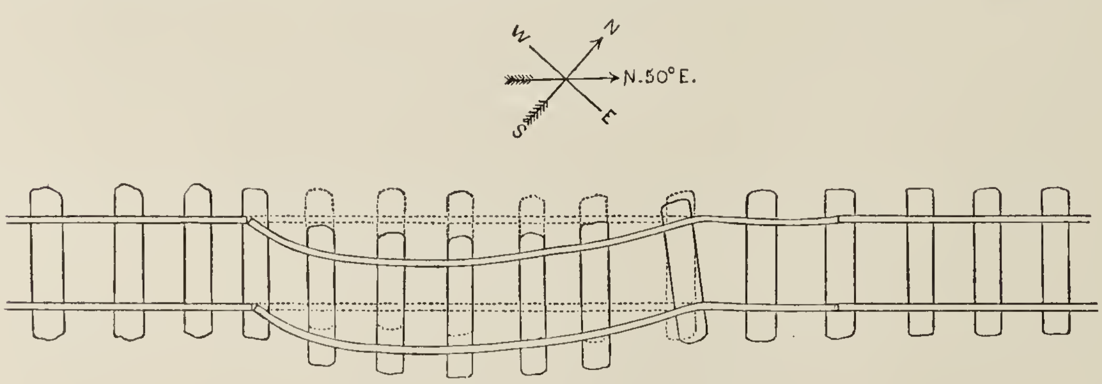
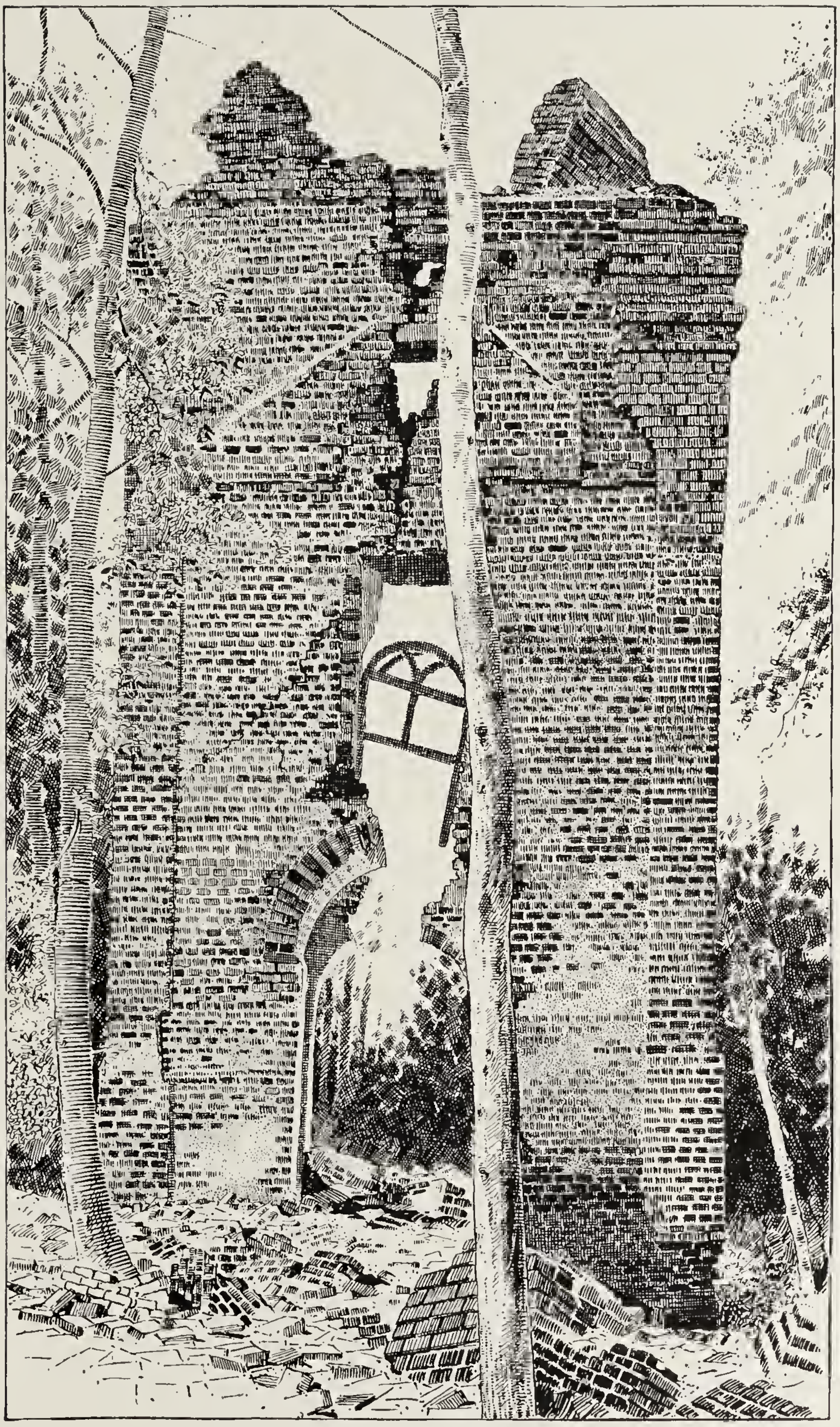



Fig. 28. Flexure of track at Gregg's.

moving had been scratched by points of the framework in contact with them. Some of these scratches were nearly a foot in length. This is believed to indicate only a part of the real amplitude.

A very interesting ruin was the residence of Dr. Baker, about a quarter of a mile north of the Ashley and about four miles above



DORCHESTER TOWER.

Lamb's. This house is said to have been built in the early part of the last century with bricks imported from England. Relatively to those times it was a very fine residence. It was solidly built, and the masonry bears evidence even now of being of the most substantial character. The house is approached from the county roadway beneath avenues of ancient live-oaks, whose heavy trunks, widespread branches, and dense shade would create a pang of envy in the heart of an English duke. The ruin of the house was complete. The northwest and southeast walls were wholly overthrown and the greater part of the northeast or front wall. The rear wall was partially prevented from falling by the bond of the interior partitions and by the bracing of the back building. The interior partitions remained, and it is to this fact that Dr. Baker owed his escape from death or serious injury. He had just retired for the night, and his bed was placed in the innermost corner of the room.

A mile and a half south of the Ashley River, along this section, the intensity showed a marked diminution. The same line, however, carries us in the course of two or three miles into a region which was powerfully affected by the second focus. Here we will merely note in passing that there is an apparent minimum between the two epicentral tracts.

SEC. VI.—The section along the southeast line is represented by the South Carolina Railway in the direction of Charleston. As this has already been discussed, it may be passed over without further mention.

SEC. VII.—The facts presented along a portion of this section, which extends due east from the epicentrum, have been partially considered in the description of the disturbances suffered by the Northeastern Railroad and some buildings in its vicinity. Some further facts, however, remain to be added to make the discussion more nearly complete. For the first four miles from the epicentrum the facts presented in such a way as to afford indications of the intensity are somewhat scanty. The country is forest clad, and contains but few habitations, and these are only small wooden cottages or negro cabins, all of which show that they were most violently shaken. The ground is reported to have been severely cracked and in several tracts the craterlets were abundant and the discharge of sand copious. In others the cracks were dry. The intensity indicated was very great. At the point where the Northeastern Railroad crosses Goose Creek the disturbances have already been described. Beyond the railroad the ground generally indicated great force, but artificial objects are scanty. Two miles to the east of it Mr. Sloan notes indications of a violent swaying of the trees. The pines were frequently "boxed" (i. e., scored by the removal of the bark and outer sap wood on one side) for the gathering of turpentine. The rosin in time becomes caked where it collects upon the exposed wood

and in the violent gales the bending of the trunk cracks it off. The unusual amount of resin here cracked off during the earthquake and the distance at which it fell were believed by Mr. Sloan and by residents in the neighborhood to have been due to the great swaying of the trees. Near by the ground was severely cracked, and many craterlets appeared, which had discharged large amounts of sand. A mile and a half farther eastward, near Foster Creek, the craterlets became large, and emitted water in such volume as to flood a rice field. The cottages were severely shaken, but suffered no worse damage than the loss of chimneys. The vertical and horizontal motions were both strongly pronounced at this point. The former was indicated by the manner in which chimneys were cracked and injured, and the latter by the displacement of furniture in the houses. In one house a bed was wheeled across the room, carrying its occupant with it. At this point Mr. Sloan notes a decided diminution of intensity, though the remaining energy was still very considerable. This decrease becomes much more marked farther eastward on the Cooper

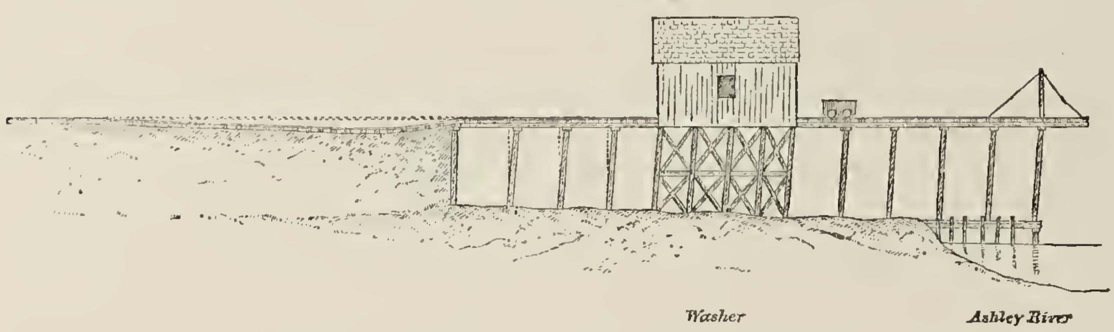
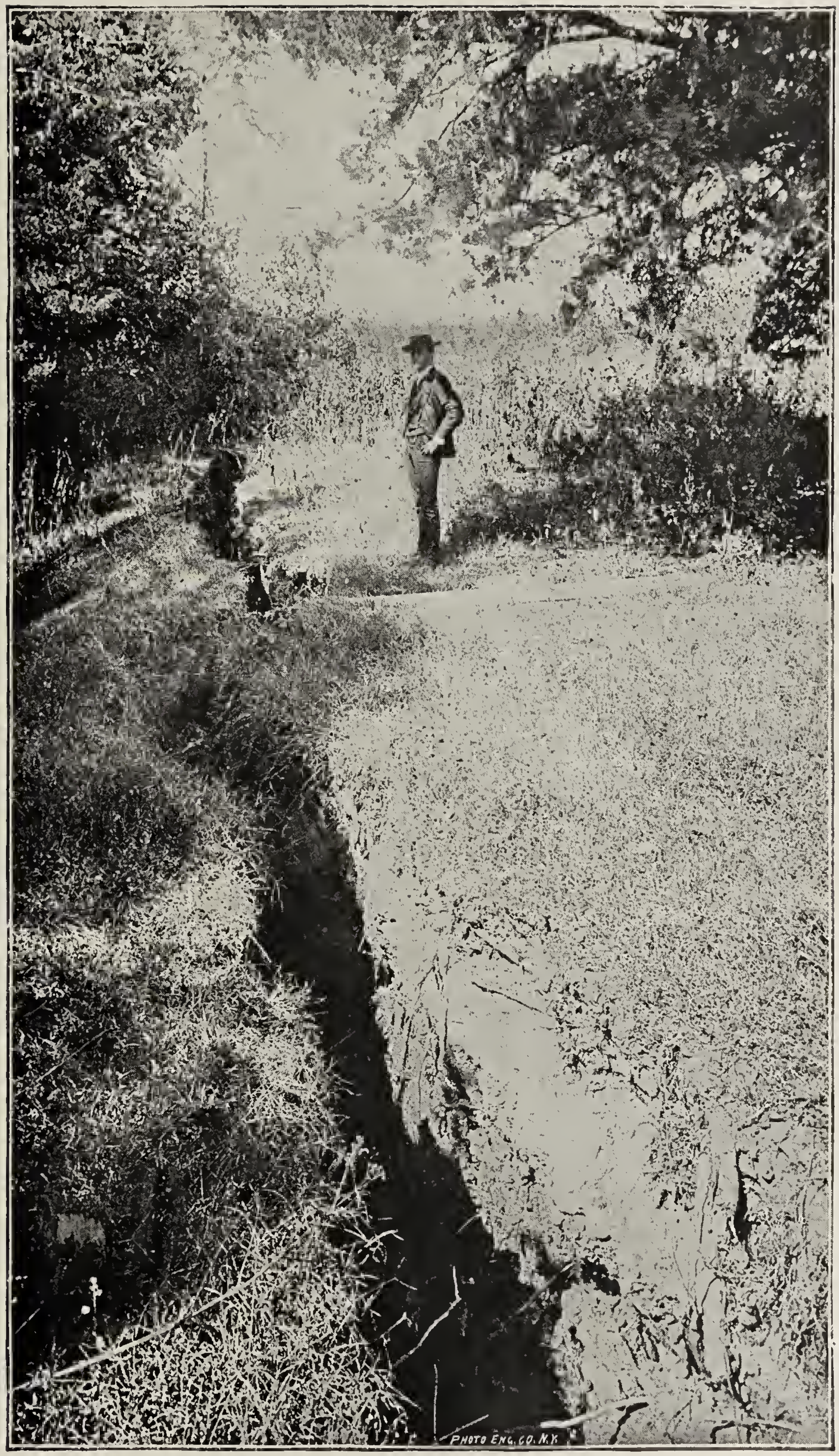



FIG. 29. Sinking of a railway embankment.

River, at what is known as the Poppenheim place, where the injuries were not of a serious character, being most conspicuously represented by a general overthrow of the chimneys of the houses scattered along the bank of the river.

SEC. VIII.—This section has been virtually described in the portion of this chapter which relates to the Northeastern Railroad. It extends northeastward from the epicentrum.

We may now proceed to a graphic delineation of the facts presented along the several lines of section, which shall show at a glance the distribution of the energy as we infer it from effects. This task might seem at first a very difficult one, because of the impossibility of assigning any definite degree to the energy displayed or of even employing any definable unit with which to measure it. No doubt this difficulty is a serious and an unfortunate one. But it is by no means fatal. Our estimates must be expected to fall far short of accuracy, and they are in some sense guesswork. But, on the other hand, these errors of estimate belong to what is usually termed the accidental class, where a considerable number of erroneous estimates have a mean value whose error is much smaller than the probable




FISSURE ON THE BANK OF THE ASHLEY RIVER.

error of any single estimate, and the danger that they will grossly mislead us is not very great. In Pl. XXIV a series of curves has been drawn, whose ordinates represent the estimated relative intensity along eight lines of direction from the epicentrum as a central point. The lines of direction are "oriented" in the drawing to correspond to their true positions on the ground. The intensity curve, which must be imagined as being drawn in a vertical plane, is represented as revolved 90°, so as to fall in the plane of the paper, the line of direction being in each curve the axis of rotation.

Before proceeding to draw final conclusions from the facts just discussed and summarized concerning the Woodstock focus, we will proceed to a similar but briefer analysis and synthesis of the facts presented by the southern epicentral tract. That a second well-marked and distinct focus existed in the vicinity of the 20-mile point of the Charleston and Savannah Railway became apparent in an early stage of the investigation. Indeed, the first impression was that there were three distinct foci with as many epicentra, and that the third one was situated in the near neighborhood of the Ashley River and a little west of the line joining the other two. So strong was this belief, that it was announced by the writer in a paper read before the National Academy of Sciences in April, 1887. Mr. Sloan was of the same opinion, though possibly holding it with some reserve. At the time of announcing the inference of a third focus the data had not been subjected to the thorough scrutiny and comparison they have since received, and the writer's opinion at present is very decided that the observed facts which led to that inference are susceptible of a different and much more probable explanation; that only two distinct foci existed, and that a third focus is inconsistent with many considerations which were not at first obvious, but which became so as the investigation became more critical and searching. The reality of the second focus, however, has not only stood the test of the most thorough scrutiny, but has received further confirmation, and has been placed beyond the reach of question. Indeed, no question about it has existed from the first.

We may first proceed to recite the evidences presented along the course of the Charleston and Savannah Railway. This road uses the same track as the Northeastern for seven miles out of Charleston and then leaves it, turning almost at a right angle to a course considerably south of west, leading to the Ashley River. We shall note the points by the mile-posts which begin at the terminal station of the Northeastern road in Charleston. Ashley River is about 11 miles and 3,000 feet from the terminus. Between the turnout (7-mile point) and the river, a distance of four and a half miles, the road suffered but few displacements and gave no marked indications of violence. By reference to the map it will be seen that this section courses nearly perpendicularly to a line drawn from the Woodstock

epicentrum, and if affected at all, it should have shown the action of this focus rather than that of the Rantowles focus, which was more distant and less energetic. This absence of any marked influence from the Woodstock focus may be put into comparison with the facts presented by a short branch road leading from Ten-mile Hill to the phosphate works at Lamb's. This branch also has a southwesterly course, making a large angle with a radius drawn from the Woodstock epicentrum. Although the ground along its route was cracked and dotted with many craterlets, the road itself showed no signs of serious disturbance.

At the Ashley River the Charleston and Savannah Railway suffered serious disturbance. The approach to the bridge is by a long embankment, traversing a marshy flat with an ascending grade, giving place near the bridge to a high trestle. An embankment and trestle lead to the bridge from the opposite side. The drawbridge

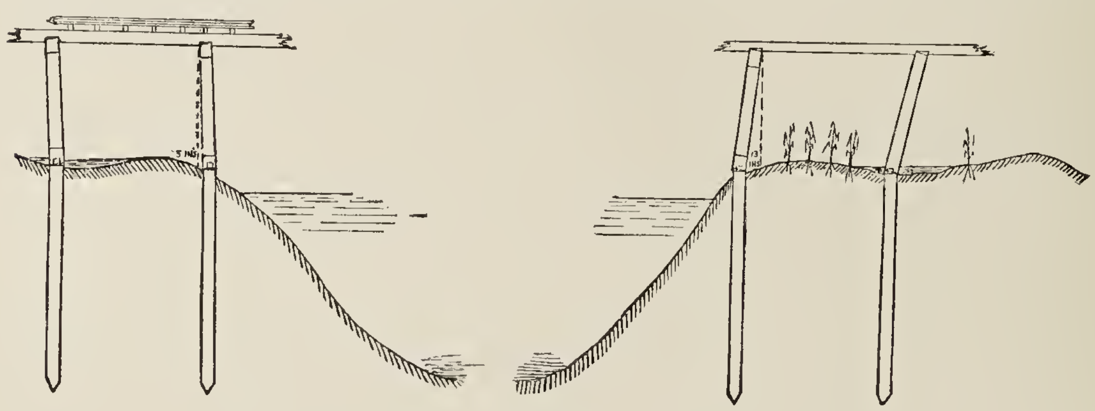
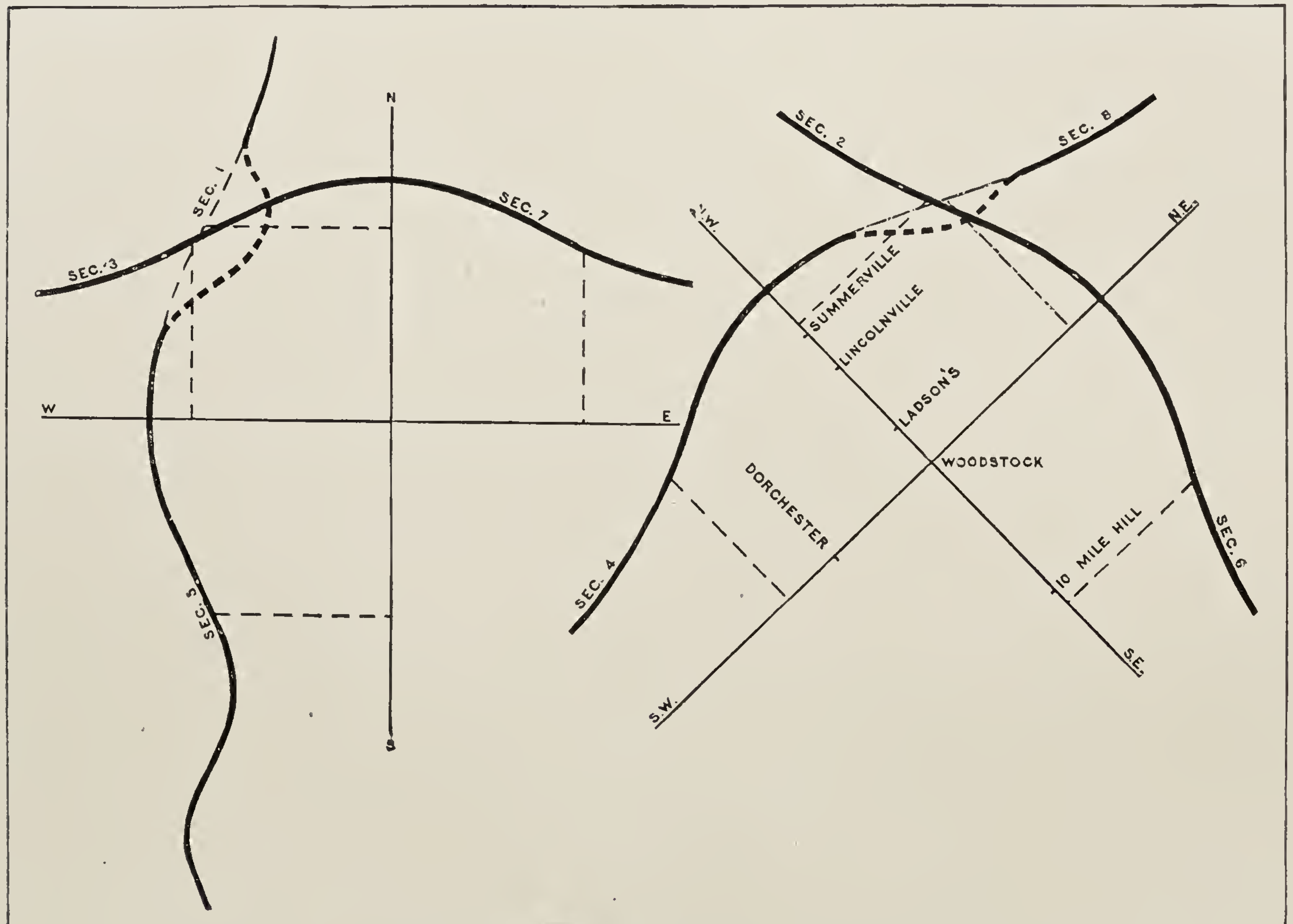


FIG. 30. Convergence of opposite banks at Ashley River bridge.

was closely jammed by the earthquake, the immediate cause being the sliding or creeping of both river banks towards the center of the stream, carrying the trestle with them. West of the river the joints of the rails were torn open by tension produced in this sliding motion. (Fig. 30.)

For a distance of four miles from the Ashley River the railroad showed no marks of serious disturbance. The country here traversed had but few objects in the vicinity of the road adapted to preserve traces of the earthquake. But on the bank of the Stono River, about three-fourths of a mile from the mouth of Rantowles Creek, indications of considerable energy were presented. Here was a phosphate washer with a tramway extending to the Stono River, standing upon marshy ground, which exhibited the same tendency to flow towards the middle of the stream as was noted at Gregg's Phosphate Works and at the Ashley River bridge. The walls of the washer were severely cracked.

As the railroad approached the Rantowles bridge signs of energy appeared to develop with great—indeed with what was probably abnormal—rapidity. At 16 miles 2,000 feet began a long flexure of




INTENSITY CURVES IN THE EPICENTRAL TRACTS.

the original straight line (or "tangent") of the road. The bridge is approached from the east over a marshy flat traversed by 1,400 feet of embankment and 1,000 feet of trestling; from the west over a similar marsh with 400 feet of trestling. Examination with a transit showed the drawbridge to be 37 inches south of its original position. The entire road-bed was distorted into an irregular curve through a distance of 7,500 feet, the maximum ordinate measured from the original straight line being at the bridge. The banks also on both sides had flowed towards the middle of the stream. Mr. Sloan adds:

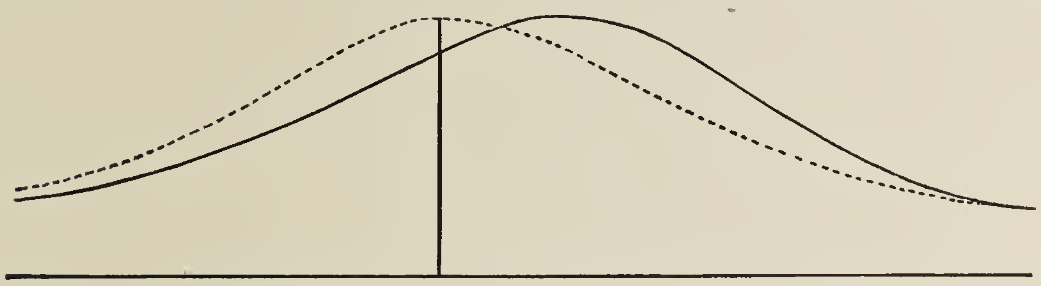


FIG. 31. Intensity curve along the Charleston and Savannah Railroad.

The piling, which affords no indication of relative movement from inclosing earth, has dragged attached bents from vertical positions and jerked the superstructure from opposite sides to the center line with violence, wrecking rails, bulging up stringers, forcing up the caps of bents which were mortised with 4-inch tenons, and in general affording liberal indications of shortening of the distance separating banks. The superstructure on both sides of the drawbridge was violently flexured both transversely and vertically with accumulated length of rail. The latter is duly accounted for near summits of the involved grades, where joints are widely parted. Along the western portion of the arc, where the displacement returns to original tangent near Rantowles station, were observed long cracks on both sides of road-bed and parallel with it.

At Rantowles station (18 miles) the track for a few hundred feet showed no appreciable disturbance, but the station-house itself was severely shaken, showing the presence of well-marked vertical components. About two hundred yards beyond the station the track was sharply kinked by one of those double flexures within a distance of 40 feet, such as were observed along the South Carolina Railway. Immediately beyond this the embankment leading across a narrow swamp was depressed two feet. The road-bed showed continuous disturbance thenceforward for several miles, the deflections being both lateral and vertical. Usually they were of small amount, but in several places they were very considerable. At 18 miles 4,500 feet the 3-foot embankment showed a depression of one foot with marked indications of vertical forces. At 19 miles the lateral deflection southward was 25 inches, and this displacement had been attained gradually through a distance of about 2,500 feet, showing that a large area had been bodily shifted. The southward displacement continued to increase for 2,000 feet more until its ordinate became 50 inches. It was complicated with minor superposed flex-

ings. Along this part of the tract, beginning at 18½ miles, the craterlets reappeared in great abundance and in increasing quantity and size. The lateral disturbances reached a maximum at 20⅔ miles. Beyond that point the sinuous flexures were continuous though the final displacements were comparatively small. These continued until the 22⅔-mile point was reached, when they rapidly vanished. Here the road passes upon higher and firmer ground, which is much less liable to permanent distortion by the vorticose motions which characterize the epicentral tract of a great earthquake. The craterlets also continued to be abundant and large. Fissures in the ground of considerable length and trending a little north of east and south of west also occurred. Opposite the 25-mile point and about a quarter of a mile from the track a fissure occurred more than 2,000 feet in length with a series of craterlets upon it.

At 25 miles 600 feet was a short depression of the road-bed to a depth of six inches. At 25 miles 4,500 feet a length of 300 feet of road-bed was depressed a foot and a half. At 26 miles slight sinuous flexures reappeared in the track, and again at a little beyond the 27-mile point. The craterlets, however, were still abundant and large. At 27 miles the road-bed was undermined by one of them, which excavated a hole 8 feet long, 6 feet wide, and 10 feet deep. In many instances craterlets starting beneath the road-bed caused depressions in it and choked the ditches alongside with the extravasated sand. At 27¼ miles there was a slight lateral deflection to the southward, followed by a depression of the road-bed of about four inches. Beyond this point disturbances to the railroad were rare. The limiting line at which craterlets were found was near Adams Run (29¾ miles).

In discussing the variations of intensity along this railroad, the observed effects of the earthquake do not present so satisfactory an aspect as those along the line of the South Carolina Railway. They exhibit anomalies which we seem forced to attribute to great variability in the surface and shallow subsurface conditions, producing great differences in the susceptibility of different areas to the shocks. As we leave the Ashley River going westward, we find hardly any trace of the earthquake until within a mile of the Rantowles bridge, where we suddenly find ourselves in the midst of evidences of great violence. But on the other side of the epicentral tract the indications of violence die out very gradually. There may arise, therefore, some difficulty in endeavoring to locate the critical points we are in pursuit of. The curve shown in Fig. 31 is as near an approximation as I am able to make to a graphic representation of the intensity between the 15-mile and the 25-mile points. The normal intensity curve which approaches most nearly to it is drawn in dotted lines. Indications, however, were abundant to the effect that the true epicentrum was not upon the line of the railroad, but situated to the north

LATERAL DISPLACEMENT OF RAILROAD TRACKS NEAR RANTOWLES.

of it. The horizontal components of motion showed a tendency to convergence in a point north of the railroad. In order to arrive at more definite determinations it is necessary to review the observed facts along other lines. Unhappily they are much more scanty than those disclosed in the Woodstock tract. The country is an alternation of pine forest and swamps, with a few cabins and still fewer cottages. Structures and natural objects which could retain traces of the work of the earthquake are few, and even these few are not very instructive. The most frequent and most characteristic traces were the fissures in the ground, some of them giving vent to sand and water, others yielding nothing.

We may with advantage examine next the traces of the earthquake along a line extending north and south through Rantowles station, and in its vicinity we shall find enough to give some notion of the varying power and characteristics of the shock. In a northward direction from Rantowles the country is an alternation of forest and swamp, with a few spaces of higher and drier ground. The earth itself was here cracked and fissured, but the openings, though showing active craterlets in abundance, did not yield those copious outpours of water and sand which appeared in such great quantity to the westward. Two miles north of Rantowles a badly shattered chimney, the isolated relic of some old dwelling, was the first suggestive object encountered. It was riven with cracks at the base

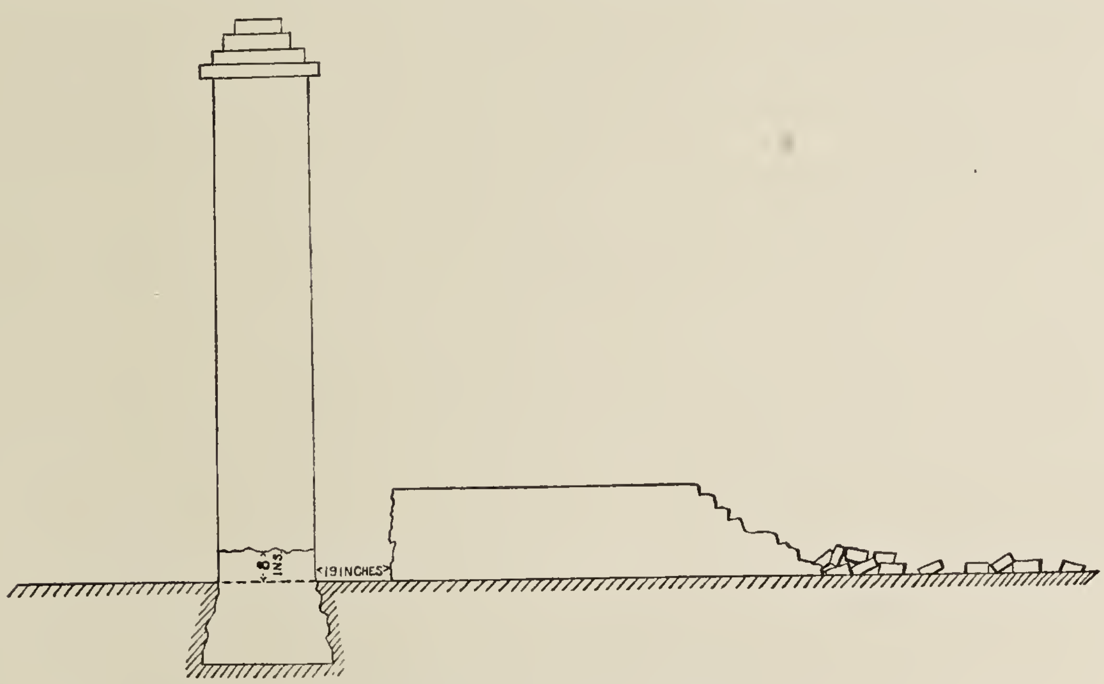



FIG. 32. Broken gate-posts at Wilkins's.

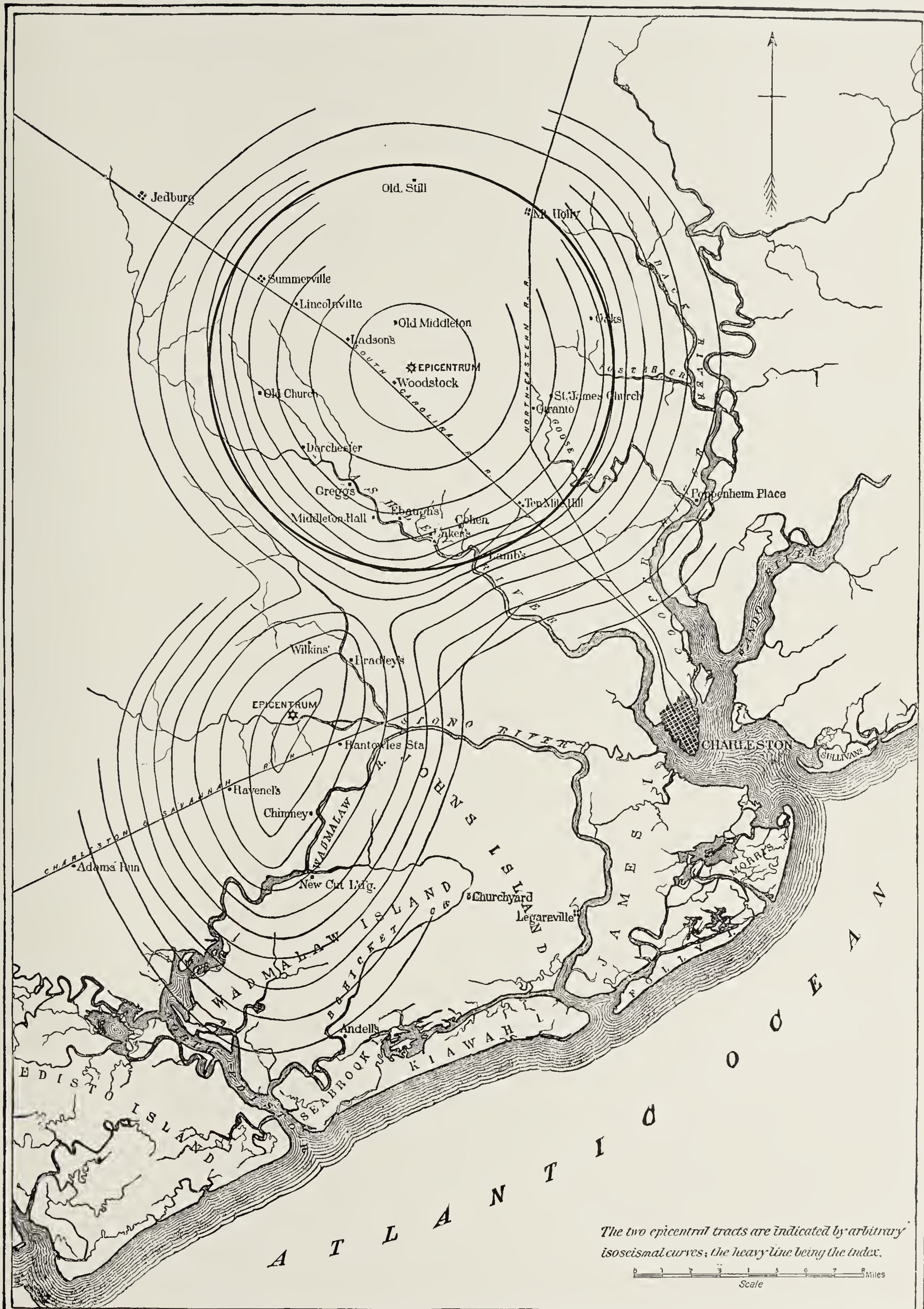
and a few feet at the top had been shaken off, indicating an action similar to that at Summerville and Lincolnville. A mile and a half farther northward is what is known as the Wilkins place. Here were some more decided and instructive vestiges. An isolated pillar which had served as a gate-post, 12 feet high and 2 feet square, built

of imported English brick with shell-lime mortar, was snapped off 8 inches above the ground. The plane of fracture passed through the bricks and not through the mortar. The upper mass was apparently projected N. 80° E., so that the edge rested upon the ground 19 inches from the base. The upper part of the fallen mass was further shattered, and some of the bricks came to rest 20 feet distant from the base. (Fig. 32.) Mr Sloan infers an accelerating force here of very exceptional magnitude. Near by this gate-post stood the walls of a brick building which had been burned. They, with their chimneys, were precipitated east and west. A little more to the northward a large chimney entirely isolated from buildings was broken 25 feet above the base, falling on all sides in ruins.

Diverging here to the eastward of our north and south line, and crossing Rantowles Creek, we find upon the eastern bank Bradley's Phosphate Works. The mining plant, though rudely shaken, was not materially damaged, being substantially framed and not susceptible to injury. But a considerable number of wooden buildings in the vicinity with brick chimneys were universally injured; the chimneys being severely cracked, broken off, and in some instances collapsed.

Proceeding northward along the line of section general indications of violence were found to be maintained for nearly two miles and then began to show marked evidences of diminution. In the examination of the southward section of the Woodstock tract the intensity was noted as falling off quite materially after passing the Ashley River. Here we meet that line of section, and note again an intervening minimum of intensity between the two epicentral tracts.

We may next examine the country south of the Charleston and Savannah Railway. Here, too, the indications are meager. The craterlets, however, are abundant and often large, discharging prodigious quantities of water and sand. About two miles south of Rantowles station, upon an elevated bluff near the Wadmalaw River, a large two-story wooden building suffered severe strain in a southeasterly direction, its plastering on the walls coursing southeast being severely cracked, and the partition wall on the second floor being widely parted to the southeastward. In this neighborhood also were a few small wooden structures disclosing very sensible injuries, the chimneys being either prostrate or seriously cracked and strained. These small wooden houses generally show no damage from any but the most intense shocks. Crossing the Wadmalaw River, other houses of similar character were found showing severely cracked chimneys. Descending the Wadmalaw River towards the southwest, about two miles from the large house above mentioned, an isolated high chimney was found to have collapsed with great violence, the fragments falling mostly to the westward. A mile and a half to the west of this spot a number of chimneys




ISOSEISMALS WITHIN THE EPICENTRAL TRACTS.

were prostrated, prevailingly to the southwest. In this vicinity the craterlets were developed on a great scale, extravasating large floods of water and volumes of sand; and in some of the holes small trees were engulfed.

At New Cut Landing, on the east bank of the Wadmalaw, was a square wooden building, three stories high, with two interior chimneys. One of them was broken off six feet below the top and projected clear of the eaves to the ground. The other was sheared off and rotated in situ. The great height of this building may account in part for the distance to which the first chimney was thrown; the amplitude of motion increasing in proportion to the height.

Mr. Sloan continued the examination along this line southward to the seacoast, and drew from his examination the conclusion that the intensity was better maintained than along transverse lines; that the isoseismals showed a marked tendency to a very elongated configuration towards the south. He believed, from the examination of the "sea islands" east and southeast of the starting point (Rantowles station), that the intensity along easterly lines faded out much more suddenly and conspicuously. In the attempt to delineate his estimates of intensity by isoseismal lines, as shown in Pl. XXVII, he has greatly emphasized this impression. I am unable to judge of the soundness of his deductions because of the uncertain character of the data set forth in his notes. On the other hand, the general impressions obtained by so careful and prudent an observer as Mr. Sloan are entitled to great weight; for the experienced geological field observer is well aware that his convictions are in similar cases based in a great measure upon very many facts which are not capable of being reduced to a formal description in writing. Yet it has seemed to me that this distortion of the isoseismals may perhaps in some measure be more apparent than real, and may be in part explained by the lack of evidence. It will be noted that there is a large tract of country east of the Rantowles bridge from which there is not a single observation recorded. In one of his supplementary notes he says:

> Along middle and east of John's Island [which lies in the southeasterly quarter from the Rantowles bridge] damage inappreciable. But few chimneys severely damaged. Legareville but slightly affected. Indications of violence increase as we approach Bohicket Creek [which is near the mouth of the North Edisto and southwest from Legareville].

As regards the northwestern part of John's Island, he merely notes that small buildings showed "chimneys severely cracked." At a considerable distance to the southeast, in an old churchyard, two large slabs, over four feet high and six inches thick, set into their bases with cement and with iron pins, were overthrown. He further informs me that the absence of indications of great energy upon John's Island is all the more surprising because there are

numerous objects there which might have been expected to show them.

Northwest of the Rantowles epicentrum there is a similar want of evidence. For the first two or three miles, however, the ground itself betrayed the most emphatic signs. The craterlets were very numerous and large and many of the fissures long and wide. The line of section soon passes into swamp and forest, where no indications appeared.

Altogether it is apparent that the Rantowles epicentral tract is defective in evidence, and it is not possible to represent the distribution of the energy with such detail as in the Woodstock tract. It is not so defective, however, as to be valueless, and we shall proceed to extract from it whatever the observed facts may justify.

## CHAPTER IV.

### THE DEPTH OF FOCI.

The earliest attempt to estimate by rational methods the depth at which an earthquake originated was made by Mr. Robert Mallet in his celebrated work upon the Neapolitan earthquake of 1857. His method was founded upon the following considerations: An earthquake tremor is a wave in an elastic medium (the earth), having much in common with a wave of sound in the air. From the center or locus of disturbance it is propagated in every possible direction. The seat of the tremor at any instant of time is a thin spherical shell whose center is the origin of the impulse. The principal motions which it causes, and those which occasion the greatest and most conspicuous damages to structures, are vibrations in a direction coincident with the radius of the spherical shell. If then, in Fig. 33, O represent the origin of the disturbance, AB a line upon the surface of the ground, and the concentric circles about O be the sections made by a vertical plane through a succession of wave-shells, the direction of the principal vibration at any point (for instance, P), will be in the direction of a radius OP. The angle APO he terms the angle of emergence. If the angles of emergence could be accurately determined at two or more localities they would at once furnish the means of computing the situation of the focus. For by the hypothesis they diverge from it; and conversely, knowing their divergence, their point of convergence at once follows. It therefore turns upon the practicability of determining the angle of emergence. Granting that more or less error must attend any such determinations, Mallet proposed to make a large number of them, in the belief that the error of the mean result would be very much smaller than the probable error of any single observation. To ascertain the angle of emergence he relied upon cracks produced in brick walls; his view being that under the sharp, powerful blow of an earthquake wave near the epicentrum these cracks would show a conspicuous tendency to arrange themselves in lines and planes perpendicular to the direction of wave motion.

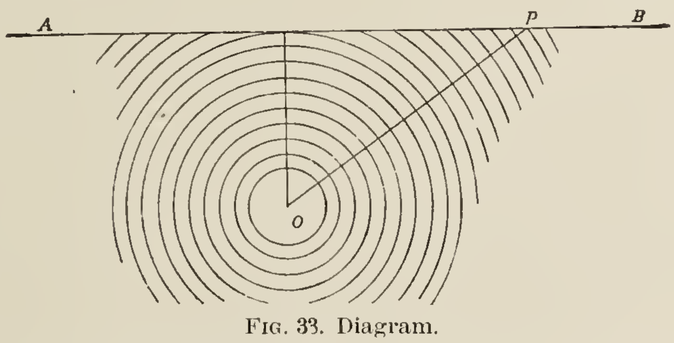


Fig. 33. Diagram.

It is very generally agreed by most seismologists that the cracks

produced in buildings do not follow the rule laid down by Mr. Mallet. Nor are the motions in the epicentral tract so pronouncedly of the "normal" character, nor so free from transverse components, that the true angle of emergence would be directly disclosed by the cracks even if they did tend to arrange themselves perpendicularly to the direction of the most powerful incident forces. This method of arriving at the desired result, therefore, must inevitably be futile. Undoubtedly, the normal vibrations, which in the epicentral tract have directions near the vertical, are often more conspicuously displayed in that tract than elsewhere; but this is not sufficient. It may, however, be of great use as corroborative evidence whenever the vertical motion is conspicuously revealed.

In a subsequent report, presented by Mallet to the British Association for the Advancement of Science at its Leeds meeting in 1858, he set forth another method, which he believed might be available, under favorable conditions for computing the depth of the focus. His view was as follows: The efficiency of a normal vibration in overthrowing standing objects depends upon two quantities; first, the energy of the vibration itself; second, the direction in which it is exerted. The energy of vibration, in common with all forms of vibratory energy which radiate from a center, decreases in a ratio proportional to the inverse square of the distance from the origin. The direction in question is the horizontal component of the normal wave. This is zero at the epicentrum, and increases as we recede from it. The net result of these two opposing quantities (intensity and direction) is, that the power to overthrow objects has a maximum value in any given normal wave when its true angle of emergence is 54° 44′ 9″.[1] There is a closed circuit around the epicentrum approximating

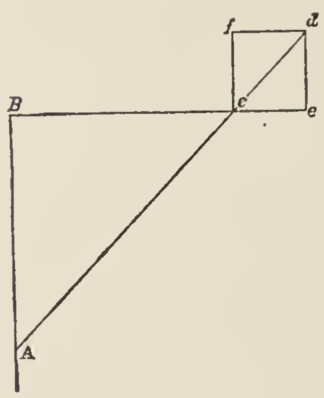
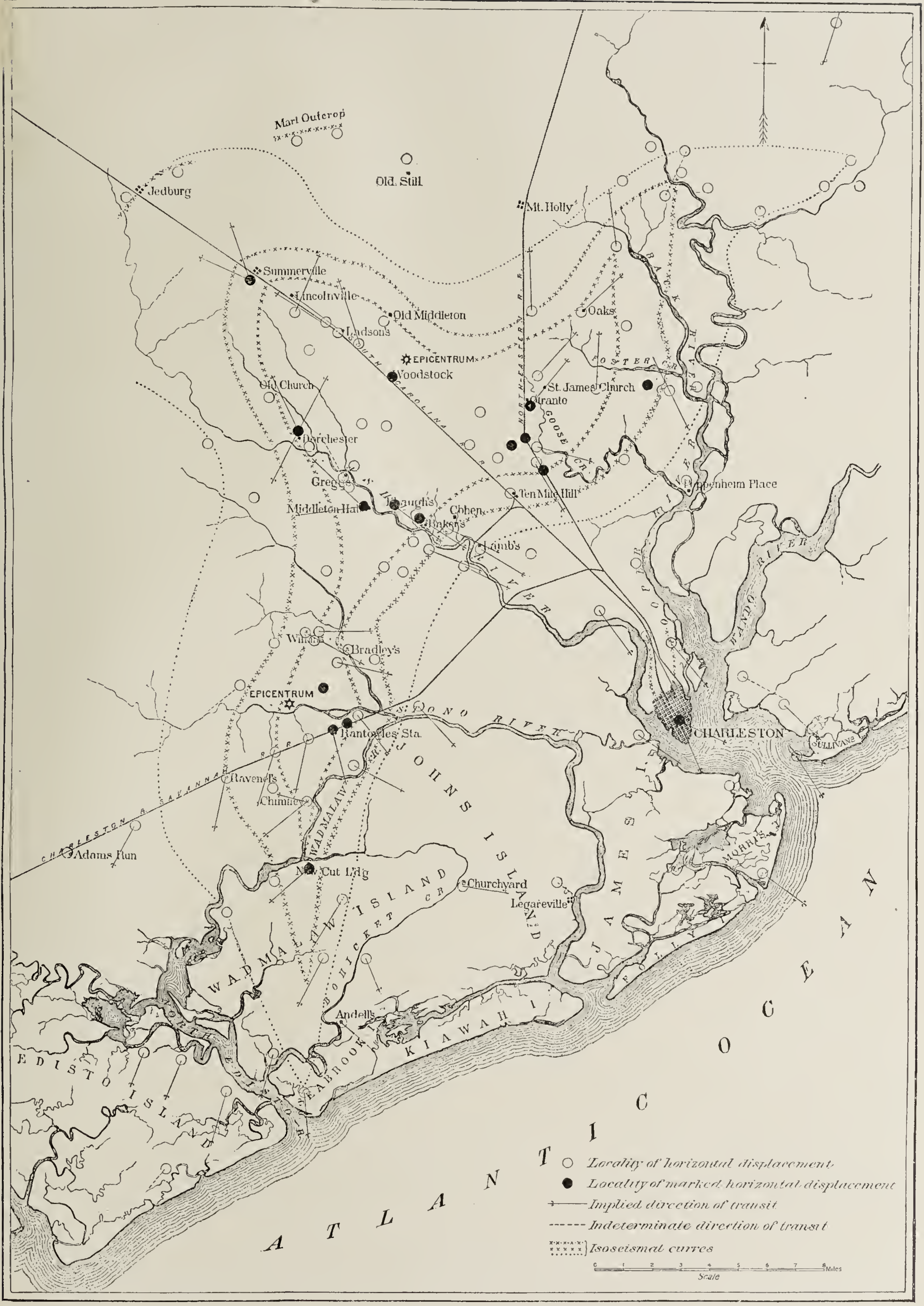


FIG. 34. Diagram.

[1] The proof given by Mallet is as follows: Let A, in Fig. 34, be the origin of the wave and B the epicentrum. It is required to find a point, C, at which the horizontal overthrowing effects of an impulse in the direction AC whose intensity varies inversely as the square of the distance shall be a maximum. Produce AC to $d$ and complete the parallelogram of forces, $fd$ being parallel to the horizon. Let BA $= a$, the depth of the origin: BC $= r$, the distance from the epicentrum when the horizontal force is a maximum; AC $=$ the normal due to $r$ as radius; and the angle $c\,de =$ BAC $= \theta$. The force at C in the direction AC is $\frac{1}{a^2+r^2}$; and that in the direction of the horizon is $\frac{\sin\theta}{a^2+r^2}$; and as $\sin\theta = \frac{r}{\sqrt{a^2+r^2}}$, we have $\frac{r}{(a^2+r^2)^{\frac{3}{2}}}$ a maximum. Differentiating $dr\,(a^2+r^2)^{\frac{3}{2}} - 3\,r^2\,dr\,(a^2+r^2)^{\frac{1}{2}} = 0$: whence $r = \frac{a}{\sqrt{2}}$. That is to say, $r : a :: 1 : \sqrt{2}$. For this proportion the value of the angle of emergence must be 54° 44′ 9″. Admitting Mr. Mallet's premises, his mathematical work and conclusion are quite correct. (Rept. of the 28th Meeting of the British Association for the Advancement of Science, p. 101.)




MR. EARLE SLOAN'S DELINEATION OF ISOSEISMALS IN EPICENTRAL TRACT.

more or less nearly to a circle where this maximum overthrowing force ought to manifest itself, unless the topographic features and conditions of ground in general are extremely irregular. This circle may be regarded as the base of an inverted cone whose apex is at the origin or focal point and every line from the focus to this circle meets its plane at the foregoing angle. The position and depth of the focal point at once follows, whenever we can locate the position of the circle of maximum overthrowing effect.

The objections to this method Mallet has pointed out. The argument proceeds upon the assumption that the critical circle of maximum overthrow is to be ascertained by discriminating the effects of normal waves alone. The transverse waves are neglected. If the effects employed for this purpose were produced at a very great distance from the origin and at a low angle of emergence, such a discrimination, though still difficult, might in favorable cases be possible. But, as they occur near the epicentrum with a high angle of emergence, the transverse waves can not be neglected; neither can their effects be readily discriminated from those of normal waves. Here the combination of the two waves is not only intricate, but it is far more so than Mallet supposed.

In a preliminary notice of some of the results obtained by the study of the Charleston earthquake read by Mr. Everett Hayden and myself before the National Academy of Sciences, in April, 1887, a different method was proposed of dealing with the facts, with a view to deriving from them an estimate of the depth of the focal point. It was then suggested that under favorable conditions the variation of intensity along lines radiating from the epicentrum ought to manifest an approximate agreement with a theoretical law easily found and expressed in mathematical terms, and from which the depth could be inferred. In seeking for the facts upon the ground which might indicate this variation, no attempt should be made to separate transverse from normal vibrations, but the estimate of intensity should take account of the total energy irrespective of direction or kind of vibration. The full power of the wave must make itself felt at the surface somehow, and must disclose effects proportional to its intensity if there is any object susceptible to its vibrations so placed as to receive them. According to the plan proposed it was only needful to study the variation of intensity along given lines upon the ground, and it was unnecessary to trouble ourselves with attempts to discriminate between normal and transverse effects. Let us first proceed to find the typical law in accordance with which the intensity should vary along a straight line upon the ground passing through the epicentrum. Let $O$ be the focal point situated at the depth $q$, beneath the epicentrum $E$. (Fig. 35.) Let the intensity of the shock (amount of energy per unit area of wave front) at the distance unity from $O$ be denoted by $a$. Since the intensity is inversely

proportional to the square of the distance, the intensity at the epicentrum would be $\frac{a}{q^2}$. Take any other point on the surface of the earth at the distance $x$ from the epicentrum and connect it with $O$ by the line $Ox=r$. The intensity at any such point will be $\frac{a}{r^2}$. If we denote the intensity at any point $x$ by the symbol $y$ we shall have the equation:

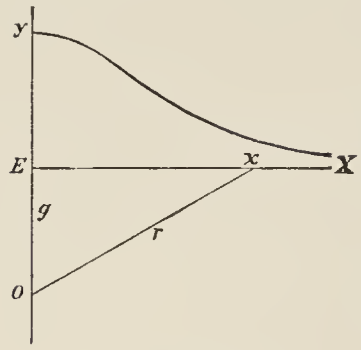


FIG. 35. Diagram.

$$y=\frac{a}{r^2}=\frac{a}{q^2+x^2}.$$

This equation expresses a curve which will serve as a graphic representation of the way in which the intensity varies along a line radiating from the epicentrum. The first noteworthy feature of this curve is the contrast between the rapidity with which the intensity diminishes near the epicentrum and the slowness with which it diminishes at great distances from it. Thus, at a distance from the epicentrum equal to the depth of the focus the intensity has fallen one-half; at twice that distance, to one-fifth; at three times the same distance, to one-tenth of the intensity of the epicentrum. It will be noticed that the curve has a point of inflection in each of its two branches. At that point its inclination to the line $Ex$ is greatest. The corresponding phase of intensity which this point of inflection denotes is, that at a distance from the epicentrum equal to the abscissa of the point of inflection the intensity declines most rapidly. If we were to start from the epicentrum and travel in a straight line away from it we should find the intensity diminishing slowly at first, but more and more rapidly until we found it dying out with a maximum rapidity. Proceeding still farther, it would continue to decline, but at a diminishing rate of change. The point at which the rate of decline is greatest corresponds to the abscissa of the point of inflection. We are assuming, of course, that the intensity manifests itself in accordance with the law of the inverse square of the distance from the origin, and that it is not obscured materially by local inequalities of the ground. Similarly in all directions from the epicentrum and at equal distances from it there should be a point where the intensity varies with maximum rapidity. The *locus* of maximum variation is therefore a circle, whose center is the epicentrum. If, now, we can find the dimensions and true position of that circle, the depth at once follows. There are several remarkable properties of this *index-circle*, as I shall call it, which we will proceed to discuss.

To find a general expression for the position of the point of inflection in any intensity curve drawn in a vertical plane through the

epicentrum, we have only to take the equation of that curve already found

$$y=\frac{a}{q^2+x^2}$$

and differentiating it twice, place the value of the second differential co-efficient equal to zero:

$$\frac{d^2y}{dx^2}=\frac{8ax^2-2a(q^2+x^2)}{(q^2+x^2)^3}=0$$

which equation is satisfied when

$$\pm x=\frac{q}{\sqrt{3}},\quad y=\frac{3}{4}\cdot\frac{a}{q^2}$$

In this value of $x$ it is seen that the constant $a$ (intensity at unit distance) has disappeared, and the abscissa of the point of inflection is independent of the original energy of the shock, and is dependent upon the depth alone. The meaning of this is, that the distance from the epicentrum to the point where the rate of decline of intensity is greatest is simply proportional to the depth of the focus, and is equal to that depth divided by the square root of 3. It is unaffected by the original intensity of the shock. This property of the point of inflection makes us independent of any absolute standard of measurement for the intensity, and all that we require is to find the points where the intensity falls off most rapidly. The depth of the focus follows at once.

Nor is it necessary that we should establish by independent evidence the position of the epicentrum. For if we can locate satisfactorily the position of the circumference of the index-circle, the epicentrum must be the center of it; in other words, it is inferred and not established by direct observation.

If we imagine the intensity curve to be revolved around the "seismic-vertical" (the vertical line at the epicentrum) as an axis, it will generate a surface resembling one of the cymbals used in an orchestra. Let us call such a figure an "indicator." Then every earthquake shock must have, ideally at least, its own "indicator." Its form and dimensions for any earthquake wave will depend upon two quantities only; first, the original intensity of the shock at the focus or at unit distance from the focal point; and, second, the depth of the focus. The dimensions of the "index-circle" will depend upon one quantity only, the depth of the focal point. This, however, proceeds upon certain assumptions which may or may not be realized in the actual earthquake. It assumes that the shock originated not indeed in a point, which would be wholly inadmissible except as a mathematical abstraction, but in a subterranean tract which was sensibly spherical or which had three co-ordinate dimensions (say length, breadth, and thickness) about equal. It also assumes that the intensity truly follows the law of the inverse square of the distance. How closely these assumptions are conformed to in the

actual occurrence of the earthquake is a question for future consideration. We are concerned at present only with conditions which may be regarded as typical. The consequences of modifying conditions must be treated by themselves. With this understanding we may next inquire how the form of our indicator is affected by varying values of the two quantities which determine it, viz, depth of focus and original energy of the shock.

Let us first suppose that the total energy of the shocks in several earthquakes is the same, but that the depth varies. The first series of curves (Fig. 36) will represent relatively the varying surface intensities. Rotating each curve about the seismic vertical will give the forms and dimensions of the "indicators." The index-circles would have radii simply proportional to the several depths of foci. The shallower focus would give a vastly greater intensity in the epicentral tract; but as the distance from the epicentrum increased the intensity due to the shallow focus would approximate rapidly the intensity due to the deeper ones. At a very great distance the intensity would be sensibly the same whether the focus were shallow or deep, provided the original energy of the shock were the same.

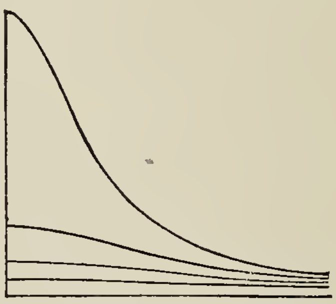


FIG. 36. Intensity curves, variable depth, constant energy.

The second series of curves (Fig. 37) is conditioned upon the assumption that the depths of several shocks are the same, but that the total energy varies as between the different shocks. Here the radii of the several index-circles are all equal, but the intensity varies at all distances, and is everywhere proportional in a simple ratio to the energy of the shock; the comparisons being made between the effects of different shocks at equal distances from the origin. In these curves the ordinates corresponding to any abscissa are proportional to each other in a simple ratio. In the first series (Fig. 36) they are proportional to each other in a duplicate ratio.

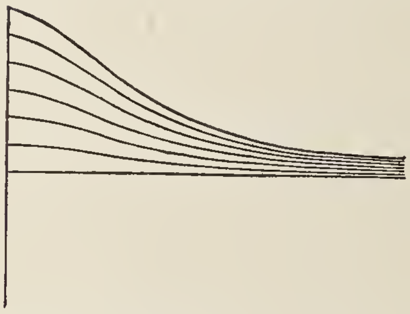


FIG. 37. Intensity curves, constant depth, variable energy.

The third series (Fig. 38) represents the effect of varying both the energy and the depth, but subject to the condition that the intensity at the epicentrum is constant.

How nearly the observed intensities in the field may approach the purely theoretical intensities is a question which can be settled only by actual trial. Undoubtedly considerable discrepancy must be expected in most cases. The variable character of the soil and of the strata near the surface may influence considerably the manifestations of energy. There is, moreover, the liability to error in estimating

the comparative intensity from different kinds of effects. Localities which were violently shaken may preserve less conspicuous and suggestive traces than others more lightly shaken, and thus mislead us in estimating the relative intensities. Nevertheless it is believed that whenever the examination of an epicentral tract and of the country around its borders is sufficiently thorough, and when the number of indications is large, these difficulties will not be sufficient to completely, or even very largely, obscure the true relations and the true rates of variation of the intensity. And if we proceed to construct an "indicator" from the estimated intensities, we shall in most cases find it approximating to some one of the theoretical forms already described. Let us proceed to construct indicators for the two epicentral tracts of the Charleston earthquake and see how nearly they conform to rational ones derived from theory.

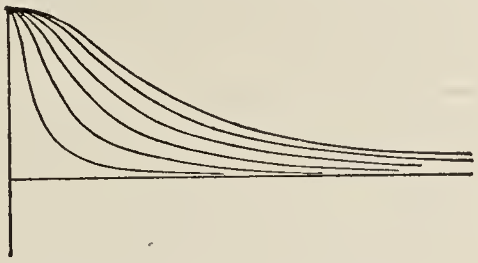


FIG. 38. Intensity curves, intensity at epicenter, constant depth, variable energy.

Pl. XXVI is an attempt to construct indicators for the two adjoining epicentral tracts by means of isoseismal lines, each running through points at which the surface intensity is estimated to be equal. These lines may be supposed to represent, after the manner of a contour map, a convex surface erected over the ground, the height of any point being proportional to the intensity at the corresponding point upon the ground beneath.

### THE WOODSTOCK FOCUS.

In the Woodstock tract the configuration of the lines is nearly circular, the deformities being everywhere slight. It will be noticed that the northern portion of the tract is left incomplete. The reason for this may be inferred from the description of Section I, given in the preceding chapter. The evidence from that quarter is scanty, indeed almost nothing. Mr. Sloan, however, interprets this absence of evidence as indicating a low intensity, being inclined to the opinion that if the intensity had been of normal degree it would have disclosed itself by indications of some kind. Not feeling qualified to hold an opinion of my own (for I did not visit this part of the epicentral tract) and yet not wholly satisfied with Mr. Sloan's guarded inference, I have left the space blank. If, indeed, an extremely pronounced earthquake shadow really occurred here the isoseismal lines would make deeply re-entrant curves in the northern quarter of the tract. But such a shadow must, if real, be due to some cause which has marked the surface action either by extinguishing the energy of vibration in its way to this part of the surface or by failing to preserve traces of it. The general conclusion to be drawn concerning the form of the subterranean focal tract

is not (in my judgment, at least) affected by this apparent defect of intensity.

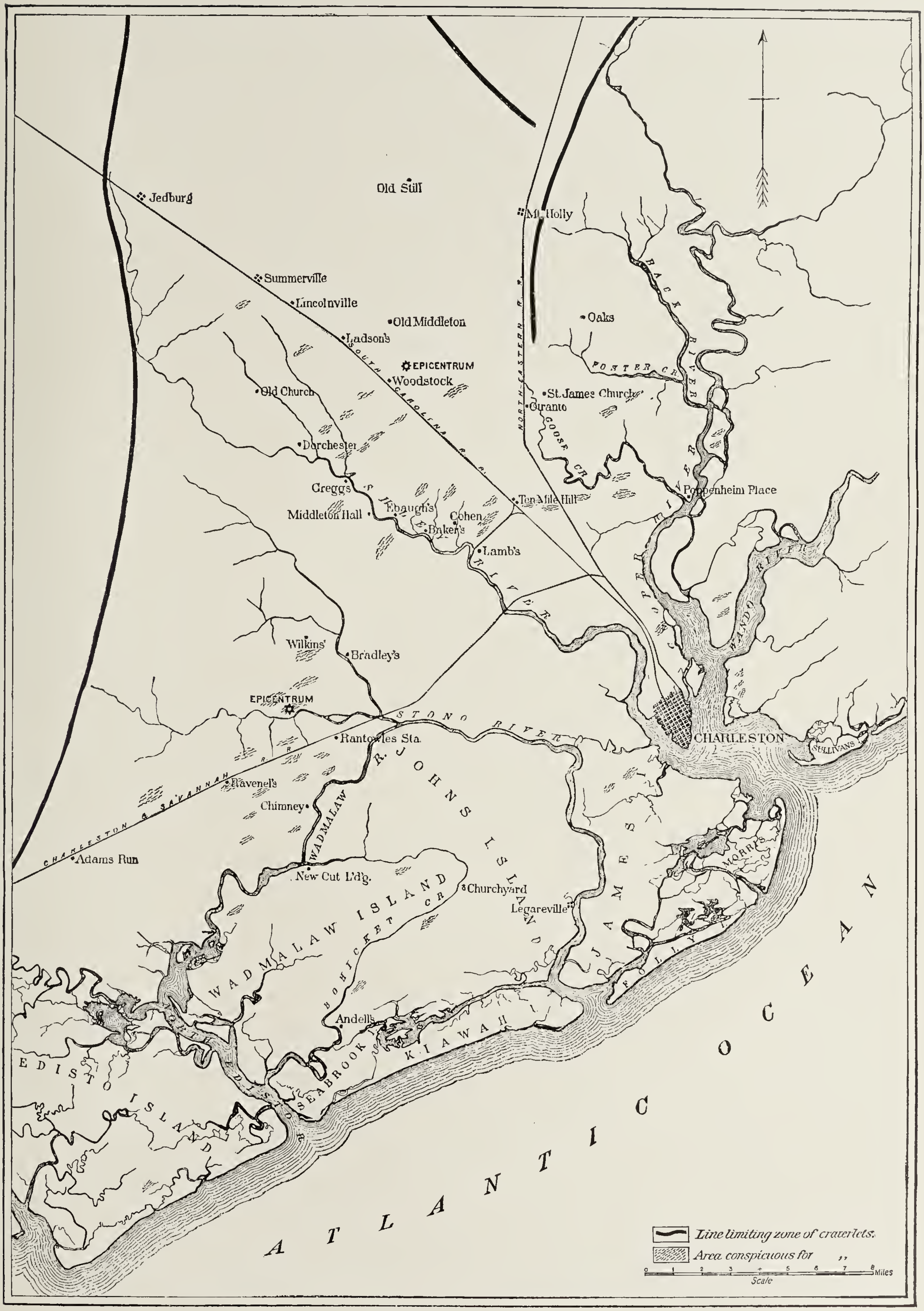
There is but one other, and that one a slight, modification of Mr. Sloan's interpretation of the facts. He is of the opinion that the isoseismal curves project considerably in the northeastern quarter. In this direction and upon the ground in question the traces of the earthquake were unusually numerous. I am unable to place the same estimate as Mr. Sloan does upon the relative intensity which they indicate. To justify this northeastern projection the intensity would require to be nearly as great as at Ten-mile Hill or at Summerville, and his descriptions do not indicate so much. Drawing the isoseismals as approximate circles would still give ample intensity in this locality to satisfy a liberal interpretation of the effects he describes.

With the data before us we can locate within a comparatively small range of uncertainty the position of the index-circle. This, it will be remembered, is the theoretical isoseismal at which the intensity diminishes most rapidly as we recede from the epicentrum. In the Woodstock tract it is inferred to have a radius of very nearly seven miles, its center (the epicentrum) being about three-fourths of a mile north of the station Woodstock. If we follow the circumference of this circle we shall find it fulfilling the requirements of an index-circle throughout three-fourths of its extent, and its failure in the remaining fourth is, with a very high degree of probability, due to the want of evidence of any kind. Sometimes there is reason to believe that the actual point of greatest variation of intensity is a little within, sometimes a little without, this circle. In all directions from the epicentrum, wherever the facts are sufficiently numerous and characteristic to justify an estimate of these variations, confidence is felt in the location of the required points with errors not exceeding a single mile.

The resulting depth of the focal point is about twelve miles, with a probable error of less than two miles. It is the product of the radius of the index-circle multiplied by the square root of 3.

That the seat of the principal shock had some such depth as this is further sustained by the fact that within the index-circle the vertical components were always extremely forcible. Sometimes they were as far outside of it, and they seldom failed to declare themselves conspicuously upon its periphery. In all this work a minor importance has generally been assigned to all inferences drawn from the direction of motion. But in the present connection the clear manifestation of vertical components is of more significance. These must in the main be due to normal waves, and when their effects are so pronounced and cover so large an area we are justified in assigning a deep origin to the shocks.

Is it possible to infer from the data obtained in the Woodstock epicentral tract anything concerning the form and dimensions of




DISTRIBUTION OF CRATERLETS.

the subterranean seat of the shocks? In reply to this question it may be said that no very definite inference seems practicable. Undoubtedly the almost circular configuration of the isoseismals suggests a very compact focus and one whose horizontal extent was not great. Its greatest horizontal dimension, in other words, is inferred to be much less than the radius of the index-circle. Nor does there appear to be any satisfactory indication of the direction in which the longer horizontal dimension, if any such there were, extended. This inference, if valid, would necessitate the rejection of the idea that the earthquake was associated with a widely extended faulting movement, shearing the rocky strata along a course of many miles. Nor has evidence of any kind been found of a movement of such a character in the country round about. The sluggish, low-grade river channels in the vicinity would serve as extremely delicate tests of any displacement; but though these have been carefully examined, they give no sign of it.

### THE RANTOWLES FOCUS.

The construction of isoseismals and an indicator for the Rantowles epicentral tract is a work of much difficulty, because the data are less numerous and decisive. They are, however, sufficient to enable us to ascertain its most important characters. The construction is represented in Pl. XXVII. It is obvious at a glance that the tract is a much smaller one than the Woodstock tract; and the curves, instead of being circular, are oval. I fully agree with Mr. Sloan that the elongation in a north and south line is well sustained by the evidence. In endeavoring to assign a depth to the focus it is obvious enough that the index-circle (perhaps it would be better to say index-circuit in this instance) should be measured by the shorter or transverse diameter through the epicentrum, and not by the longer axis. In that event the first critical point of greatest rate of change in the intensity would be located about a mile east of the Rantowles bridge, and the opposite point about nine miles to the west of the first. Thus the radius of the index-circle would be about four and a half miles in length, and the resulting depth of the focal point would be about seven and four-fifths miles—or say nearly eight miles. The oval form of the isoseismals indicates an elongated form for the seat of action, its major axis extending north and south.

The existence of a third epicentrum was at first inferred in the neighborhood of Dorchester, on the bank of the Ashley River. This inference arose from the very striking manifestations of energy at the old church tower upon the banks of the river, where some large and wide fissures were formed. Subsequent examination, however, showed that these indications would not bear the interpretation placed upon them, for when brought into comparison with other

facts it became obvious that the exceptional manifestations were due to exceptional conditions, while the general tenor of a wider range of facts indicated only a normal amount of energy. For instance, the tower of the old Dorchester church, being a high and relatively slender pile, would naturally be more affected at its summit than lower structures on broader foundations. The great cracks at the river bank were produced by a sliding towards the channel of the river, an occurrence which was repeated at many other places, where there was no other indication of abnormal intensity, and indeed in several localities where the intensity was notably less than was generally the case within the epicentral tract. In the neighborhood of Dorchester there were, besides the two phenomena just mentioned, no others to indicate abnormal intensity, nor indeed any special occurrences clearly attributable to an independent focus and epicentrum.

# CHAPTER V.

## THE EARTHQUAKE THROUGHOUT THE COUNTRY.

In describing the effects of the earthquake throughout the country at large, it is difficult to fix upon any particular order of mention which shall be logical and coherent. The table given in the appendix is a condensed statement of the reports from all localities; but it is a quarry of facts rather than a structure. To build a structure or to arrange the facts in any suggestive order is almost impossible. For want of any better method, I shall begin by setting forth such information as is at hand concerning the effects in the regions immediately outside of the epicentral tract, and in which the earthquake, though not calamitous nor highly destructive, was still energetic enough to cause considerable injury and to thoroughly terrify the whole population. As might be expected, this region forms an irregular belt or ring surrounding the epicentral tract, and having an exterior diameter of fully 100 miles. Within this belt it failed of being more or less disastrous because there was comparatively little to destroy. The country is a part of the great coastal plain of Carolina, containing a considerable number of small villages and an agricultural population. Buildings of stone or brick are comparatively rare outside of the large cities, and none of them are lofty enough to be greatly affected by the cumulated swing due to repeated impulses. Thus the injuries produced were mostly of the minor sort—the overthrow of chimneys and the shaking down of plastering. The few brick structures, however, were severely cracked, and often left in a dangerous condition, while several instances are given of their virtual demolition. The wooden structures all suffered more or less injury by the straining of timbers and shattering of glass and general destruction of plastering.

A large part of the area now under discussion is a low country, abounding in swamps and mostly covered with pine forest. It is a country little suited for the preservation of the traces of such a catastrophe. The majority of the population are black, and they live in cabins constructed of logs, or in other structures equally primitive, with chimneys composed of sticks embedded in clay. The towns and villages, which are scattered about, are not so prosperous as those situated farther inland along the Piedmont region, and they rarely contain structures which would be liable to serious damage by any earthquake, however violent. The earth itself, however, sometimes

preserved traces which are suggestive. A considerable number of reports state that sink-holes were formed by the shocks, in which the ground sank in various amounts ranging from a few inches to over 20 feet. None of these were large, the maximum being about 60 feet in diameter. These sinks were on the whole quite numerous, over seventy being reported within a distance of sixty miles from the epicentrum, and very probably there were many more of which no mention has been made.

All accounts within the region speak of the loud roar of the earthquake. Most of them describe it as a deep rumbling noises welling into a loud, harsh roar, in which detonating sounds or rattlings were intermingled. One writer very tersely and graphically describes it as thunder in the ground instead of in the air. Some accounts assert that the rumbling was heard before the quaking was felt; others that the sound and the tremors were perceived simultaneously.

There is also substantial agreement that the undulatory motion was very violent. Within 80 miles of the centrum all accounts speak of the difficulty of standing while the earthquake was at its maximum. Some say that they found it necessary to cling to fences and trees for support, and that the trees themselves swayed as if bent by a powerful gale. Others speak of falling while seeking to gain safety by flight. As is usual in such cases, no two persons agree as to the direction of motion, and from what we know of the nature of the movements caused by an earthquake no agreement is to be expected. Some of the most interesting reports come from the light-houses along the coast of South Carolina. The short and quick vibrations of individual tremors would probably not affect such structures more than ordinary buildings, but the long undulations would be greatly magnified at the tops of high towers. As the undulatory movement is reported from all parts of the country affected, it is thought best to insert here the reports from light-houses within the 100-mile limit, which are so well calculated to exhibit it, and also to indicate how far such movements may be general and how far they are complicated with other movements. It will appear from the accounts that undulatory motion, though common, was by no means universal.

### BULL'S BAY LIGHT STATION.

Bull's Island, South Carolina, 25 miles northeast of Charleston. The tower is 35 feet high. The house shook so that it jumped the lens off the pedestal. All the shocks came from the southwest. The first shock was felt at 9.45 p. m. The others "came every five minutes up to 2 o'clock, then about every half hour up to 10 o'clock the next day." (Compare with number of shocks at Charleston and at light-house on Morris Island.)

### CAPE ROMAIN LIGHT STATION.

On Raccoon Key, 10 miles southwest of the entrance of Santee River, South Carolina. The tower is 150 feet high. The keeper was in his house when the shock came.

A gradually increasing rumbling, "sounding something like a battery of artillery or a troop of cavalry crossing a long bridge," was heard before the shock in a west-southwest direction. "In less than a minute came the shocks, the first one lasting about two minutes, the next one about as long, and about two minutes' interval. Shocks, only a little less severe than the first two, were felt at intervals during the night. The shocks did the tower no injury, but its vibration was very great." Everything on the shelves and "a trap-door that leaned back at an angle of forty-five degrees" were thrown down. "All of the shocks seemed to be of a quick, rotary motion." "It seemed a miracle that the tower and dwellings were left standing," but "little or no damage was done to either, with the exception of a chimney thrown down and others cracked." About a thousand cranes nest on the key during the summer months, and these were flying about, "making a fearful noise," during the shock.

### GEORGETOWN LIGHT STATION.

Entrance to the Pee Dee River and harbor of Georgetown, S. C. The shock "lasted about one minute," and was preceded by a rumbling noise as of thunder, "the sound coming from the eastward." "The tremor seemed to be east and west." Eight or more shocks were felt, the first being the severest. "The shock was vertical."

### CAPE FEAR LIGHT STATION.

Northwest end of Smith's Island, entrance to Cape Fear River, North Carolina. Two shocks were felt on August 31. The motion of the first "lasted about ten seconds, was somewhat undulating, and passed from northwest to southeast." The shocks were strong enough "to crack and break glass (lamp) chimneys in the tower."

### CHARLESTON LIGHT STATION, ON MORRIS ISLAND.

The tower is 150 feet high. The keeper, who was standing at the door of the tower, heard a rumbling noise, and at the same time felt the earth tremble, which increased until it had a strong tearing and jerking motion. "It subsided gradually." The tower "shook and trembled terribly." "The first shock lasted about thirty seconds. The second shock succeeded the first not over two minutes," causing the same movements of the tower, but was not quite so severe. "After the second shock he went up into the lantern of the tower. When the third shock occurred, its force was such as to almost prevent him from standing on his feet. The lens swung from southeast to northwest, back and forward, about three or four times in a second. After the third shock there were several moderate ones." Eighteen were counted up to the evening of September 1. "The lens swung from southeast to northwest until about the twentieth shock, when it swung from northeast to southwest, afterwards swinging in different directions." There were many fissures in the ground, from 2 to 4 inches wide and from 10 to 100 feet in length, some running northeast and southwest, some northwest and southeast. "Two considerable cracks," besides smaller ones, were afterwards found in the masonry of the tower, which maintained its proper position.

### FORT SUMTER LIGHT STATION.

"The first shock lasted about forty-three seconds and later ones from three to five seconds. One chimney was overthrown, and the frame houses were badly shaken. The first severe shocks came with a decided jar, were succeeded by a tremulous motion, and appeared to come horizontally."

### HUNTING ISLAND LIGHT STATION.

At the entrance to St. Helena Sound, South Carolina. The iron tower is 121 feet high, and "shook so violently that the two assistant keepers in the watch-room at the top could not stand up without holding on to the railing. The second assistant keeper was on the balcony near the top of the tower when the shock occurred. He was thrown from the dome to the balcony railing back and forth. When the shock first commenced it seemed like a tremor, but increased so violently that it seemed as though the bed had been raised from the floor and shaken with great violence." The first shock seemed to come horizontally, but a fortnight afterwards, when the keeper was in the tower, a light shock occurred which seemed to come vertically, "as though some great power was thumping underneath the base of the tower," but "not strong enough to shake it."

### HILTON HEAD RANGE LIGHTS.

On Hilton Head Island, South Carolina. The keeper was in his house, near the tower. "The first shock lasted about fifty or sixty seconds; the others from ten to twenty seconds." Ten shocks were felt the first hour. "The whole tower shook and heaved like a small boat in a heavy sea" during the first shock, which "came from the southwest: the others appeared to come from the northeast, and before each one was heard a rushing sound, like the distant boom of large guns."

### PARIS ISLAND RANGE LIGHTS, SOUTH CAROLINA.

The report from this station is not clear. "The motion continued for about one and a half minutes," apparently referring to the first shock. "There were seven or eight shocks," which are described as being "moderate," although the keeper "thought the tower was coming down, and ran out." "They seemed to come horizontally." No other shock is recorded at this station until March 5.

### DAWFUSKIE ISLAND RANGE LIGHT, SOUTH CAROLINA.

"The first shock lasted fully fifty seconds. It came like the roaring of a prairie fire. There were nine shocks in all during the night. The first shock occurred at 9.25 p. m., local time," and was the most severe. "That at 9.30 seemed like a trembling wave, passing by in one second. That at 9.34 lasted fully forty seconds, and was severe. That at 9.40 was accompanied by a rumbling noise, lasting a few seconds. That at 10 lasted three seconds, and was accompanied by the same rumbling noise." "That at 10.16 lasted about five seconds, and passed like a wave." "That at 12.40 lasted about five seconds. It sounded like a shot from a rifle-cannon, and passed with the same sort of noise that a cannon-ball would have in passing through the air." Others occurred later, and all seemed to be a jar vertically. "No damage was done to any buildings, walls, or chimneys."

### BLOODY POINT RANGE LIGHTS.

Southeast end of Dawfuskie Island, South Carolina. "The shock lasted from one to two minutes. The first noise was heard as a great wave of water swashing up against the back of the house. * * * This was immediately followed by a rattling noise, as of a great number of heavy men with big boots on tramping to and fro on the back piazza. In an instant the same sort of crowd seemed to have taken possession of the front piazza, and each platoon was trying to outmarch the other. * * * Now these heavy shod feet seemed to have reached the roof and the upper floors. Then a roaring noise came, booming underground, as of heavy cannonading. During this time the house lamp was jumping like it was lifted and let drop by a

string; the house shivered; then seemed to be shoved in a horizontal plane; then the motion, noise, and all together was of riding in a car which had left the rails and was bumping over the ties on a bridge or trestle; loose things on all sides were tumbling about, adding no little to the frightful effect." The motions and noises gradually subsided, then stopped. The keeper immediately ran to the beach, a few yards distant. "There was no change in anything outside; the water did not seem to have been in the least affected." "There were nine distinct shocks during the night." The second "lasted perhaps half a minute, and ceased at 9.55." "It set things jingling." "Five minutes later the third shock came," and "seemed to affect the house differently from either of the others in a way difficult to describe. The keeper had a feeling of nausea," not before experienced, and his family were similarly affected. * * * "It was quite a violent quake. That the house would tumble from the brick piers on which it was built seemed certain. All the succeeding shocks were less severe. There was a lull from 12.46 a. m. until 4. 33 a. m., when a shock was felt that seemed to approach the station from a point a little west of north, passing off to sea." The direction of the preceding shocks is not plainly recorded, the only statement being that they approached "the back of the house."

### TYBEE ISLAND LIGHT STATION, GEORGIA.

Entrance to Savannah River. Four strong shocks were felt from 9.30 to 10 p. m., local time. The first shock "continued about ninety seconds, and was accompanied by a heavy rumbling noise, similar to thunder underneath." The tower is of brick, and 134 feet high. The wall was cracked about midway, where it is six feet thick. The lens, weighing about a ton, was moved one and a half inches to the northeast.

Throughout this region the terror and consternation of the people was great. Nearly the whole population passed the night out of doors. The negroes were panic-stricken, devoting the night to those wild ecstacies of prayer, wailing, and mutual exhortation so characteristic of the race in the Black Belt. The white population, less demonstrative and more self-contained, were still impressed with the gravest apprehensions, not knowing whether the forcible movements already experienced might not be the precursors of some catastrophe.

The 100-mile circle contains two considerable cities besides Charleston, from which circumstantial accounts of the effects of the earthquake have been received, namely, Savannah, Ga., and Columbia, S. C. Each city is about ninety miles distant from the epicentrum; Columbia to the northwest and Savannah to the southwest. The shaking was very forcible and alarming, but in neither place was it disastrous. It was certainly more vigorous in Columbia than in Savannah.

Of the effects in the latter city a very good description has been given by Signal Service Observer Richard Graham. His account is as follows:

The first shock occurred at 9 25 p. m. (standard time) of August 31, at which time the office clock stopped, and the time as noted by the observer's watch, immediately after the first shock, was 9$^h$ 53$^m$ 30$^s$. Captain New, of the British steam-ship *Annie*, lying at Tybee Roads, informed the observer that he timed the shock by his chro-

nometer, and that the duration was 1$^m$ 40$^s$. The shock was preceded by a rumbling noise, which increased to a loud roar. The first rumbling was accompanied by oscillations from southwest to northeast, and as the roar increased the oscillatory or rocking movement changed to violent and quick vibrations, which, after attaining a maximum, appeared to subside gradually as the noise became fainter. The window rattled violently, and five panes of glass were broken. The ceiling and walls of the office were cracked in several places, from which small pieces of plaster and fine mortar dropped to the floor. At 9.58 p. m. another light shock occurred, also accompanied by rumblings and slight oscillations. At 10 p. m. a third shock was experienced; this last, though not so violent as the first, was of much greater intensity than the second, and was accompanied by a rumbling noise and quick vibrations, lasting about thirty seconds. The third shock may be noted as *moderate*—No. 3 in measure of intensity. [Professor Rockwood's scale.] The shocks were apparently felt with equal violence in all parts of the city. Some persons in the streets and in the parks at the time of the occurrence state that the ground suddenly moved up and down with a wave-like motion, making it difficult to retain an upright position, while others again reported a violent trembling and shaking of the earth. On Bay street, about two hundred yards in an east-northeasterly direction from the signal office, a crack about twenty feet long appeared in the ground. The statue surmounting the Pulaski monument was moved out of position about six inches. (Fig. 39.) Chandeliers were shaken to the floor; pictures and ornaments were thrown down, and large squares of plate glass were shattered.

In order to obtain accurate report of the damage to buildings, and to determine approximately the intensity of the earthquake at Savannah, the observer called on the city surveyor, and was informed by that official that up to the present time his examination has shown ten buildings to have been seriously damaged by the shock—walls or gables being so damaged as to necessitate removal—and 240 chimneys are more or less damaged. Further examination will probably run the number of damaged chimneys up to 300. It should be stated that the damage to walls and gable-ends in all cases occurred in very old buildings, or where the work was of a flimsy character. None of the newer buildings of the city have suffered damage beyond the cracking of walls and shaking down of plastering.

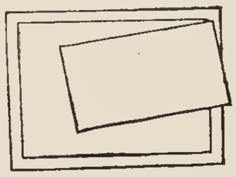


Fig. 39. Displacement of Pulaski Monument at Savannah.

Respecting the statue on the Pulaski monument, the following may be given as indicating in some measure the direction of movement of the seismic wave:

The monument faces south and north, and the statue on top of the column was moved six inches along the top of the shaft in an easterly direction and two towards the north; the distance between the northeast corner of the shaft and the statue was six inches, and the distance from the southeast corner was eight inches. Fig. 39 shows the position of the statue after the earthquake:

The reports given by the newspapers from dispatches sent over the country by the various press associations are best summarized in the account in the New York Tribune of September 2. It agrees with the more diffuse accounts given by the Savannah papers, and with those contained in a large number of letters of individuals:

[New York Tribune, September 2, 1886.—Special.]

SAVANNAH, *September* 1.

Savannah has never been more terrified than it was last night and to-day. At 9.28 p. m. yesterday a severe shock of earthquake struck the city, and in an instant everything was in confusion. The first intimation of its coming was the

approach, apparently from a northwesterly direction, of a sound resembling the crackling of a wall preceding the collapse of a brick building. Almost at the same time the earth swayed, chimneys toppled down, plastering fell in houses, and ornaments and other articles on tables and mantels. Revivals were in progress in two negro churches, and in the panic several women fainted and fell and were severely injured by the crowds who rushed over them. One negress died from fright. Negroes ran about the streets lamenting and crying to the Almighty for protection. People in every part of the city rushed from their dwellings and sought safety in the open places. Several persons were struck by falling bricks, but received no serious injury. Two white women in different parts of the city leaped from second story windows, and suffered broken bones, but were not fatally hurt. One of the women had a babe in her arms, but it escaped unhurt. The entire force of fifty or more men in the Morning News building ran into the street, and it was over an hour before the printers could be induced to return to work in the sixth story of the building, where the effect of the shock was more severe than on the street. Communication in every direction by telegraph was cut off, and the Western Union operators fled in affright. Over an hour later the press circuit was renewed, but the line to Charleston and the North was not recovered until this afternoon.

Nearly every building in the city was more or less damaged by the shock. While small in most individual instances, the financial loss in the aggregate will be considerable. In Broughton street, the principal thoroughfare, the west wall of a small brick store fell, and in Bay street the upper corner of a three-story brick building fell to the roof of an adjoining structure. The first shock was followed after an interval of two or three minutes by two additional shocks, each of which was nearly as severe as the first. Later in the night, at intervals of an hour or more, seven additional shocks were felt. None of these, however, equaled the first three in severity. Entire families spent the night on chairs in the middle of the streets and other open places, and the number of people who slept was small.

The shocks at Columbia, S. C., judging from all accounts, were more forcible than at Savannah. The first two impulses, which appear to have corresponded to the two maxima already described at Charleston, threw the whole city into a state of terror. The swaying of buildings was very great; the jarring, like that of a wagon rumbling over a stony pavement, was excessive, shaking down plaster, chandeliers, crockery and light objects, and producing a loud rattle, which, added to the subterranean roaring, caused the greatest consternation. The cracking of brick walls was apparently much more common than at Savannah. The undulatory motion of the earth is described by many as being so great, that for a few seconds walking was extremely difficult and possible only with great care and attention to the footsteps. Still no instances have been reported of the demolition of any buildings.

The most remarkable circumstance, however, connected with Columbia is the fact that a considerably greater intensity is indicated for that city than for the localities to the southeast of it nearer to the centrum. There is, indeed, a belt of country along the Piedmont region where the same state of affairs prevailed, and this belt coincides with a marked change in the geologic formations. It is that belt where the Tertiary-Cretaceous system of marls, sandstones, clays and quicksands forming the great coastal plain and lower Pied-

mont region terminate and the more ancient metamorphic crystalline rocks appear. In South Carolina and in adjoining portions of Georgia and North Carolina the unconformable contact of the older and later rocks is found, stretching from northeast to southwest. Towards the ocean are the later formations, while to the northwestward lie the older rocks of the Southern Appalachian region. A line drawn from the earthquake centrum to Columbia would cross the line of contact of the two stratigraphic systems almost perpendicularly. The earthquake impulses leaving the centrum declined in energy towards the northwest at a rate which seems to be a natural one, so far as can be judged from the accounts at hand. But as they approached the line of contact of the younger beds with the older, the energy seems to have increased for a time as the waves sped onward. Thus at Orangeburgh, which is 32 miles nearer the centrum than Columbia, the account given by Prof. R. Means Davis leaves little doubt that the violence of the shocks was notably less. Nor was Orangeburgh exceptional in this respect when compared with other localities similarly situated with reference to the contact lines of the strata. Similar accounts indicating a more moderate energy come from many other places in the same county; also from Barnwell, Williston, Statesburgh, Camden Junction, and Sumter. But if we proceed northwestward from these places until we reach the older metamorphic rocks we find traces of increased vigor.

Thus Augusta, in Georgia, just beyond the 100-mile circle, was shaken with great violence. Many buildings were seriously damaged. At the arsenal two heavy walled buildings used as officers' quarters were so badly shattered that reconstruction was necessary. Many cornices were dislodged and it is estimated that more than a a thousand chimneys were overthrown. People residing in brick dwellings refused for several days to enter them, and found lodgings in wooden houses or camped in the streets and gardens. So great was the alarm felt, that business and society were for two days as fully paralyzed as in Charleston. Every one was in a state of apprehension that the worst was yet to come and the only thing to be thought of was safety. Indeed, among all the large cities of the South the general tenor of the reports indicates that Augusta stands next to Charleston in respect to the degree of violence of the shocks and the consternation of the people.

Augusta is built in close proximity to the contact of the newer and older strata, and starting from that city it will be of interest to follow this line of contact northeastward. In detail the course is more or less sinuous. A few miles to the northeast of Augusta is a little railway station named Langley, where a small tributary of the Savannah River has been dammed to secure a water power. The ground in this neighborhood, which is a loose soil thinly covering harder rocks below, was in many places fissured by the earthquake

and opened in many cracks, some of which were several inches in width. A number of large cracks passed through the dam, opening passages for the water in the reservoir, which quickly enlarged the fissures. The country below was quickly aflood. The railway track was swept, and before warning could be given a passenger train ran into the flood and upon the broken track, where it was wrecked, with some loss of life. In this neighborhood the towns of Bath, Graniteville, and Vaucluse, which stand upon outcrops of crystalline rocks, report shocks of very great severity. Still farther to the northeastward, Batesburg, Leesville, and Lexington give similar reports. Passing beyond Columbia along the same line of contact, we find reports of very violent shocks at Blythewood, Camden, Chesterfield, and Cheraw.

Throughout the State of North Carolina the vigor of the shocks was very great. Not a locality which has been interrogated has failed to report proofs of intensity sufficient to arouse and alarm the entire population. Not a village escaped minor damages, such as the loss of chimneys and plastering; and wherever brick structures exist the accounts of cracked walls are frequent. There is, however, a notable difference as a general rule between the eastern part of the State within the coastal region and the Piedmont and mountain region. It was notably less forcible in the coastal plain. In Wilmington, N. C., the shocks, though alarming everybody and shaking buildings with an energy that caused no little apprehension, did not produce the complete consternation which seized upon all classes in the towns and cities of the interior; and this statement holds good in full view of all qualifications which might be expected to arise from the different distances of localities from the centrum. The light-houses upon the North Carolina coast suffered but little from the shock and rarely gave any indications of a great amount of disturbance. There are many indications that the vast masses of littoral deposits of unconsolidated sands, clays, and marls along the Atlantic border and coastal plain, especially in the Carolinas, greatly tempered and modified the force of the earthquake. It may be said that they "cushioned" the shocks, not elastically, but by actually dissipating in some measure portions of the rays of energy which here affected the surface. This fact gives us a somewhat different rate or law in the variation and decline of intensity as we proceed northeastward along the coast as compared with the rate along lines radiating from the centrum in other directions. The decline of intensity is abnormally rapid along the coast for the first 150 or 200 miles. At greater distances the intensity is more nearly constant, being maintained by the energy of deeper waves.

Turning to the Piedmont and mountain regions of North Carolina, we find indications that the shocks were more forcible than at equal distances along the coast. At Raleigh (215 miles) they were almost

as severe, and I am led to infer that they may have been quite as severe as at Wilmington (152 miles).

[Associated Press Dispatch.]

RALEIGH, N. C., *August* 31.

Earthquake shocks were felt here to-night, beginning at 9.50 o'clock and continuing nearly six minutes. Buildings rocked, walls cracked, floors broke loose from their supports, chimneys fell, and lamps were overturned. The shocks lasted over five minutes. The motion of the earth was very decided. The streets rapidly filled with people, screams of frightened persons could be heard, and negroes were in great fear. Such decided shocks were never before felt here. Reports show that the shocks were felt all over the State. At Wilmington they were very severe and came near wrecking several buildings. It is safe to say that no such excitement was ever known here as this earthquake has caused. The shock here rang the church bells; it also threw down plastering and rang door bells in houses. The second shock came at 10.4 and lasted about half a minute. The third shock did not come until 10.30 and was very slight. It shook houses very sensibly, however. The movement of the earth from the west was very perceptible. In the first shock houses soon acquired a swinging or oscillating movement, the steadiness of which was remarkable. In the News and Observer office the shaking was similar to that felt in the press-room when engines and presses are running. There was a pause of a quarter of a minute in the first shock, when the earth seemed to balance itself. The excitement at this hour (10.45) is not at all abated. Very few people are asleep and nearly all houses are deserted. Some people will remain out of doors all night, no doubt, through fear. The weather to-day has been fine. There was rain at 8 o'clock, but at the time the shock came the sky was unclouded.

[Associated Press Dispatch.]

ASHEVILLE, N. C., *September* 1.

At 9.45 o'clock last night a rumbling like that of the running of heavy machinery in the basement of the houses was heard, and it was instantly followed by a rattling of windows and furniture. Those who had retired, and even those sleeping, were aroused and rushed frightened from their houses into the streets. Terror-stricken men, women, and children, in night dress, crowded the streets in a moment, some carrying their babes not yet awakened. Heavier grew the rumbling, and as buildings began to shake and walls to vibrate the streets and open places were sought by the rushing crowds.

The earth trembled and bells tolled in the church towers, and the people in consternation prayed or stood dazed in the streets. A number of ladies fainted. The negroes began a religious meeting in one of the churches, which was kept up all night. At about 11 o'clock another shock was felt, but not as alarming as the first. At 1 o'clock there was another shock, and the last shock came at daylight. None of the three later disturbances were anything like so great as the first, but at 1 o'clock a sound like that of distant heavy cannonading was heard. No buildings were shaken down, but it seems wonderful that they escaped. Pictures fell from their places on the walls, lamps were displaced, and chandeliers swung to and fro.

At Weaverville, eight miles north of this city, a congregation stampeded and some women and children were injured. The services, however, were continued, and the anxious seat was crowded with penitents. Near Waynesville, 30 miles to the westward, several chimneys were thrown down by the shock. At Charlotte, 80 miles east, two houses were shaken down and a number of buildings injured.

At Asheville (220 miles), at Salisbury (195 miles), and at Charlotte (163 miles) it is very difficult to distinguish from the accounts

at hand any notable differences of intensity from that disclosed at Raleigh. In the mountain regions near Asheville the shocks are reported to have manifested variable force. In the Black Mountain they were accompanied by loud explosive sounds and heavy rumblings, and large masses of rock were dislodged from several steep ledges and rolled down into the valleys below. Other small towns in the neighboring regions report a decidedly lower degree of intensity.

Passing into the central and northwestern part of South Carolina we find every accessible point in the State reporting shocks of considerable violence, alarming the whole population. The reports from this section are, however, insufficiently detailed and precise to enable us to make a very satisfactory estimate of the intensity. The region as a whole is a mountainous one, and the effects varied considerably even in adjoining localities. It is apparent, however, that in the vicinity of the contact line between the older and younger rocks already referred to the violence was not only great but universally distributed. To the westward and northwestward it gradually decreased, so that in the northwestern corner of South Carolina its force may be described as exciting rather than alarming.

From the eastern part of Georgia the reports are very numerous, and they all indicate a high degree of intensity. The condition of the people was one of consternation, but not of demoralization, as in South Carolina. The negroes, however, betook themselves to religious exercises after their peculiar manner in every place where a sufficient number of them could be got together to make a "meeting." Nor were the whites altogether free from those feelings of awe and solemnity which incline men to invoke superhuman aid and protection. The damages to structures, however, were all of the minor kinds. Many chimneys were overthrown, walls were slightly cracked, and plaster dislodged. Very many instances are also reported of lamps overturned, water thrown out of tanks, cars set in motion upon side tracks, animals filled with terror, fowls shaken from their roosts, loose objects thrown from shelves and mantels, pictures banged against the walls, chairs and bedsteads moved horizontally upon the floors, trees visibly swayed and their leaves agitated and rustled as if by a strong wind. The roar of the earthquake was everywhere noted, and perhaps there was no characteristic which showed a more definite relation to the progressive enfeeblement of the shocks with increasing distance than the gradual diminution of the sound as the impulses moved onward. It is easy to trace in the large number of reports a steadily decreasing amount of notice or attention to sound as the distance from the centrum increases.

Passing to the seacoast of Georgia and northern Florida, we discover the same indications of a rapid weakening of the shocks which has been noted along the coast of North Carolina on the opposite side of the centrum. Proceeding southward along the Atlantic coast

of Florida the vigor steadily diminishes, so that when the end of the great peninsula is reached it has either vanished or become a tremor so faint that it is noticed in but a few favored spots. At Brunswick and Darien, Ga., the energy was great and of an alarming kind. At Jacksonville, Fla., while still forcible, it was considerably less, and thence southward its decline was rapid.

We have thus discussed the features of the earthquake within those limits where it may be said to have been severe, and these limits may be said to range between two hundred and two hundred and fifty miles from the centrum. We may discuss the remainder of the region affected by it much more summarily and with an eye to general rather than to local features.

The first consideration to be noted is the magnitude of the area affected by the shocks. It was sensibly felt in Boston, which is the most distant point on the Atlantic coast at which it was perceived, though there it was extremely light. From Maine only negative reports have been received. Most of the reports from New Hampshire are also negative, but two or three of them seem to indicate that it was felt in that State in sensitive spots. In Vermont affirmative replies are made at St. Johnsbury and Burlington, as well as at points farther southward in that State. No positive reports come from the province of Quebec. In New York State it was felt in the vicinity of Lake George and at Lake Placid and Blue Mountain Lake in the Adirondacks. In Ontario it was observed in many places, though a large number of the reports from that province are negative.[1] Among the places in this province which give affirmative reports are London and Sarnia. From the southern peninsula of Michigan the evidence is clear that it was generally noted by persons who were favorably situated. The most distant point in this State which has given a detailed statement of well-marked tremors is Manistee, a town situated on the shore of Lake Michigan well northward towards the straits. Crossing the lake, we also find it to have been observed at Green Bay, in Wisconsin. It was very perceptible at Milwaukee and at other towns in the same State. A detailed report of the tremors also comes from La Crosse, on the upper Mississippi, about nine hundred and sixty miles from the centrum. This is the most distant locality within the United States which has furnished clear and unquestionable evidence that the earthquake was distinctly felt and recognized as such. At Prairie du Chien, a little lower

[1] One of the most interesting observations comes from Toronto, where the meteorological service of Canada has established a set of magnetographs for recording magnetic variations. These delicately balanced instruments have proved not only in this but in other earthquakes to be exceedingly sensitive seismoscopes, and being connected with a most accurately rated clock, afford approximate means of determining the time of advent of the shocks. The observations furnished by Prof. Charles Carpmael are discussed elsewhere in this work by Prof. Simon Newcomb.

down the Mississippi, the tremors were well marked. A number of places in the eastern part of Iowa give circumstantial accounts of the shocks. At Dubuque they were quite decided, and created sufficient alarm among the occupants of upper rooms in the higher buildings to cause a hurried flight into the streets. Similar accounts come from Davenport, Burlington, and Keokuk. Several places in the interior of the State also report it. The indications from Des Moines are somewhat doubtful. Throughout the eastern and central part of Missouri the tremors were felt and noted in many localities, though some places in the same region give negative reports. Careful inquiry was made to ascertain whether they were felt as far west as Kansas City. One statement of a doubtful character at first suggested that it might have been noticed there, but the final result of the inquiry is strongly against the probability of it. In eastern Arkansas the shocks were also well observed, and in the northeastern corner of Louisiana they were most probably sensible. They were clearly so in New Orleans, but throughout the remainder of Louisiana the reports are all in the negative. There was also a conspicuous rarity of sensible tremors in the southwestern part of Mississippi.

Inquiry was also made to ascertain whether the shocks were felt in Central America, the West Indies, and Bermuda. From Yucatan the reports were negative. From Cuba numerous affirmative reports were received. The most distant locality in that island giving an affirmative answer was Sagua la Grande, where the vibrations were well marked and their character unmistakable. It is not a little remarkable, however, that they were unnoticed in the West India Islands. From Nassau, New Providence, the report is negative. From Bermuda, however, a letter has been received which leaves no doubt that the tremors were faintly felt there by a few persons favorably situated for observing them. This island is almost exactly a thousand miles distant from the centrum

The area within which the motion was sufficient to attract the attention of the unexpectant observer would thus be somewhat more than circumscribed by a circle of a thousand miles radius, and the area of sensible shaking would, including the oceanic area, roughly approximate two and one-half million square miles. In this estimate only distinct, well-defined tremors, perceptible without the agency of instruments, are included. It is probable that by proper instrumental observation the disturbance could have been detected over a much greater area. It is also to be noted that the peripheral portions of the observed area lie in districts some of which are thinly peopled, others containing less intelligent and observant inhabitants, like the lower St. Lawrence Valley, the remoter parts of Ontario, the black parishes of Louisiana, and the Everglades of Florida. Some of the peripheral parts of the disturbed area, like the

Delta region of the Lower Mississippi, are not well adapted to disclose the nature of the passing shocks. Furthermore, the waves in the outer portions of the area were almost everywhere of great wave length and comparatively slow oscillation, and, while still retaining a large amount of energy, did not often resolve themselves into those shorter tremors which are much more likely to attract attention, though really possessing much less energy. Many hundreds of miles from the origin the long swaying motion was felt and was often sufficient to produce seasickness, yet was unaccompanied by sound or by the tremulous motion due to short waves.

These considerations may serve in some measure to explain several noteworthy facts in the distribution of the disturbance. Thus it is seen that the extreme range of sensible tremors is greatest towards the northwest, in the direction of southwestern Wisconsin and southeastern Minnesota, tending to make the boundary line of the disturbed tract a square, with a rounded corner, rather than a circle. South of La Crosse the course of the marginal line is never far west of the Mississippi River, and it actually crosses that river to the eastward in Louisiana. Thus the limit of sensible tremors becomes less and less remote from the centrum as it approaches the Gulf of Mexico. In the Delta region of the Lower Mississippi there is a conspicuous tendency of the isoseismal lines to crowd together. Viewing the same fact in another aspect, the shocks, which were of normal energy in the uplands of Georgia, and north and north central Alabama, grow weak with abnormal rapidity as they pass into the Delta region, and prematurely vanish in the southwestern part of the State of Mississippi. I can not help regarding this as an illustration of the view already expressed, and to be adverted to again and again, that wherever great bodies of imperfectly consolidated sediments cover the profounder rocks, in which the main energy of the earthquake wave is transmitted, so much of the energy is dissipated that the surface effects are greatly enfeebled. The Delta of the Mississippi thus presents us the same fact and the same explanation as we have already observed along the Atlantic coast on both sides of the centrum.

Having thus noted briefly the regions where the earthquake was severe and traced the border line where its vibrations became imperceptible, we may bestow a hasty glance upon the intermediate regions, where the intensity was "light," "moderate," and "strong."

In western Massachusetts and in Connecticut all the larger cities and towns indicate that its effects were very perceptible, but usually in the upper stories of high buildings. The smaller towns, which seldom contain high buildings, generally give negative reports. In the valley of the Hudson and in northern New Jersey the shaking was much more noticeable and was far more generally observed. In New York City thousands of people were aware of it in spite of the

incessant jar and rumble which characterize the metropolis. The account given by the New York Herald is worth preserving.

[New York Herald, September 1, 1886.]

In the city department of the Herald building, on the third floor, the oscillations were felt with alarming distinctness. As nearly as can be judged it was five minutes to 10 o'clock. The waves of motion seemed to flow on a line extending from east-southeast to west-northwest. The motion was so well defined that it was sufficient at each recurrence to press some of the writers who were at work against the tables. Electric wires suspended about the room swayed back and forth. A heavy electric lamp, covered with a screen and standing on a slender brass rod, swayed laterally to and fro with a sweep of three-quarters of an inch for more than fifty seconds. There were two series of vibrations, the first lasting about twenty seconds. Then there was an interval of four or five seconds, and again a series of stronger oscillations covering perhaps thirty-five or forty seconds. While the first series lasted only two or three of those who were present seemed to be aware of it. They began to ask each other, "What was that?" "Did you feel that tremor?" and similar questions, and then it ceased. But while they were still questioning each other and discussing the second series of earth waves set in, and then all who were present felt the motion and saw the swaying of objects in the room. The duration of this second series was such that persons could move about the room watching the manifestations of the earth's erratic action.

While on the lower floors of the Western Union building the shocks were not noticed, away up near the roof they created quite an excitement. In the operating room, on the seventh floor, the vibrations brought the clicking of the instruments to a standstill until the tremors ceased. Several of the operators jumped from their seats, supposing that the west wall was falling out. The swaying of a switchboard while the vibrations lasted seemed to convince the more nervous of the telegraphers that the building was giving way. Before the operators could leave their desks, however, the shivering ceased, and then they felt assured that it had been caused by an earthquake. A large recording instrument which writes out messages was in operation when the shocks began, and during the moment they continued all the words that had passed over the wire were recorded by one continued blurr on the tape. No damage was done to any of the instruments.

In the rooms of the Associated Press, on the top story, during the minute or less that the shocks lasted, desks, tables, and chairs seemed to be swaying. The motion was described by all as from west to east and back again. It was "a gentle, wavy sort of a shake," as an operator said, and still one that made persons so high up and so far away from the street wish for the moment that they were somewhere else. The waves had only stopped rolling when the reports began to come in announcing that the earthquake had been felt hundreds of miles away from the city. In the Western Union building the time that the shocks occurred was marked down as eight minutes to 10 o'clock.

Steward Bennett, of Gouverneur Hospital, in Gouverneur slip, was sitting in his room, on the top floor of that institution, reading a newspaper, about five minutes to 10 p. m. He felt the chair vibrate beneath him. He dropped his paper, an', turning to his wife, said: "It seems to me that the floor is shaking." Going to the female ward on the same floor, the steward and his wife found the nurse and patients in great excitement. They all feared that the building was about to topple over. Their fears were quieted when assured that no danger existed. The patients in the male ward also plainly felt the shock.

Eastsiders living along the line of East Broadway and adjacent streets were treated to the "shock" at about 10 o'clock, the curious phenomenon being observed by many persons. The shock appeared to them to move from west to east and

was of several seconds' duration. As near as could be learned the feeling was experienced by parties in Canal street, East Broadway, and Rutgers street. At No. 169 East Broadway a large, substantial, tenement house, the inhabitants, mostly Germans and Poles, were enjoying the cool air, when a sudden vibration, which caused the building to sway perceptibly, sent every one to the street below. For a time the greatest excitement prevailed and the jabbering scene at the Tower of Babel was re-enacted. Then the excitement began to subside, and the people returned, wondering, to their homes, undecided whether they had felt an earthquake or an explosion.

The shock was not felt at any of the institutions on Blackwell's or Ward's Island. No shock was felt at Bellevue Hospital, or in any of the buildings on the grounds.

Officer Andy Kelly, of the Union Market Police Court, was notified at midnight by his son that the earthquake had wrought considerable damage to their home at the corner of Avenue B and 7th street. He found that the walls were badly cracked and in places the plastering had fallen from the ceiling. Frightened by the threatening appearance of the entire building, the family were obliged to leave their home. The policeman notified the Fire Department, and an official was sent at once to the building. An examination showed that the building was unsafe, and the occupants were warned to remain away.

The clerks in the general post-office and the sergeant on duty in the basement of the City Hall declared that there had been no earthquake, and when informed that such was really the case refused to believe the news. All the policemen doing duty along the streets were equally ignorant of the fact that the ground had been swaying beneath them.

The upper portion of the city was visited last night by the shock at three minutes to 10 o'clock, as nearly as can be judged, the shock lasting for one and a half minutes. While it caused the greatest consternation among the residents on the west side of the town, the shock, if any, on the east side was but slight. During the prevalence of the vibrations people rushed frantically from houses and flats into the street, many in night garments, carrying children in their arms.

Mr. Henry Allen, ticket-seller on the "L" station, 125th street and Eighth avenue, said to a Herald reporter: "I was selling a ticket at the time the shock came, and I remarked to the man at the box that I had 'never felt the structure shake like this.' No train was approaching at the time from either direction."

A lady who came on the station platform afterward said: "I was in a private residence at the time visiting friends. When the shock came I became seasick from the rocking motion, but made my way with the rest to the street. Everybody was out, even to the children, who had retired some time before."

Mrs. Charles E. Merritt, wife of the assistant manager of the Mackay-Bennett cables, felt the shock very perceptibly, and left her apartments in the Berkshire flats, 125th street and Eighth avenue, seeking the company of her neighbors.

Mrs. Robert E. Livingston, in the same building (the Berkshire), was passing through the flat at the time, when the pictures and other furniture began to rock. The tenants of this building, which occupies a block front, ran into the main corridor, when each corroborated the other's statement.

The Winthrop, a six-story family hotel, occupying a block on Seventh avenue, between 124th and 125th streets, is occupied by 300 persons. Here the shock was very violent, many of the women fainting and the greatest excitement existing for some time. They congregated in the halls and reluctantly returned to their rooms.

John Brunton, of No. 208 West 123d street, a subcontractor on the aqueduct, was seen by the reporter. He said: "I thought it was one of my dynamite houses in action, and rushed out and telephoned up the road. I felt reassured when they said everything was all right. My house shook like a leaf, and through the neighborhood everybody was alarmed."

On Eighth avenue and 121st street the block swarmed with tenants and their children, who labored under the greatest excitement. The policeman on post tried to quiet the people and carried many of the children into the houses. All the high flats on the west side of Harlem experienced the shock.

A reporter, who between the hours of 8.30 and 12 o'clock traveled through the west side of the city between Charles and Hudson streets and Tenth avenue and 59th street and touching at the following points, Seventh avenue and 11th street, Fifth avenue and 15th street, 20th street and Eighth avenue, Tenth avenue and 37th street, 47th street and Ninth avenue, neither felt nor heard anything of the earthquake, nor did any of the police officials in those precincts seem to be aware of it.

Two distinct shocks of an earthquake were felt in Brooklyn. The first was very perceptible at police headquarters, in the municipal building—it was at 9.45 o'clock—and at 10.17 o'clock the second vibration was so violent that the desks swayed to and fro with an easy motion. The chandeliers moved to and fro, and the telephone bells in the several instruments commenced to ring. At first it was thought that a gas-meter had exploded, but investigation showed that the vibrations were very similar to those felt about two years ago. In the streets near the City Hall a number of people congregated to compare notes regarding the vibration.

Capt. William Gear, one of the telegraph operators at the police headquarters, was sitting at the telephone instrument taking a message when he felt the first shock. It was just at 9.45 o'clock. He described his sensations thus: "I was frightened when I felt myself rocking to and fro, and the first thing I thought of was that I had an attack of heart disease. I placed my hand over my heart, and, getting up, I noticed that the chandelier over the switchboard was shaking. I also noticed that a number of the 'drops' on the telephone switchboard had come down. Then it struck me that it was caused by an earthquake shock. I sat down again, and at 10.17 o'clock I experienced the same feeling. It made me sick."

Captain Gear had hardly finished his story to a Herald reporter when Sergeant Healy, of the Gates avenue police precinct, called up the telephone and asked the operator, "What was that I felt a minute ago? Was it an earthquake?" The operator replied that it was.

Sergeant Cullen, of the Congress street police station, also said that he felt the shocks while sitting at his desk writing up the daily blotter.

Sergeant Phillips, of the Bridge police station, on Sands street, said he felt a strange motion of his chair, but paid no particular attention to it.

A Herald reporter, who was on Hancock street, near Bedford avenue, felt both shocks. The vibration seemed to be from west to east, and it was so violent that the chandeliers in the parlors and on the second floors of the houses swayed back and forward, and the occupants became frightened and ran down to the street, where they congregated on the street corners and discussed the matter.

The bell in the steeple of the Bedford Avenue Reformed Church, corner of Madison street, rang twice, and it is presumed that the ringing was caused by the vibration.

On Fulton street and on Bedford avenue the shocks were very perceptible, and nearly every corner was crowded by persons who were more or less frightened.

In every case the vibration was from west to east, and the section of the city in which the two shocks were most felt was between Sands street and Atlantic avenue.

The tremors in New York City and Brooklyn must be regarded as very light. While thousands of people noticed them, there were tens of thousands, and even hundreds of thousands, who did not. The vibrations were felt almost wholly in the lofty buildings. Upon the ground they were rarely perceived, though a few reports are given by persons at rest who were conscious of them and understood

their character. No case has been reported from New York City where a person walking in the street suspected an earthquake.

In New Jersey the tremors appear to have been a little more decided. A large number of towns give reports which indicate an intensity sufficient to attract the attention of almost any person in a state of rest, while many in large buildings were somewhat alarmed. In Newark and along the valley of the Passaic River it was noted by many people. The lighthouses of the New Jersey coast invariably give affirmative reports and describe the oscillations of the high towers.

Many towns in the valley of the Hudson and Mohawk also report observations. It is a little remarkable, however, that Syracuse, Utica, Rochester, and Buffalo give either negative or doubtful reports, while smaller towns in the vicinity give decisively affirmative ones. Still more remarkable is the fact that, if we were to judge from the face of the reports alone, the average intensity for the State of New York, though very light, was not more so than that for central and eastern Pennsylvania. Early in the process of collecting data there appeared to be an abnormal defect both in the number of reports obtained and in the intensity indicated by such reports as were received from the greater part of this State. The western counties near Pittsburgh gave abundant returns and indications of intensity which seem rather excessive. The defect was in the remaining part of the State. Prof. J. P. Lesley was appealed to, and by his courteous assistance a more searching canvass was made. The result in my judgment indicates that the defects of intensity were real throughout the greater part of Pennsylvania. In Philadelphia it seems to have had about the same degree of force as in New York City. A small portion of the people observed it and recognized its character, while the great majority did not. It was felt only by those in the upper stories of large buildings. In Harrisburg it has not been possible to find a single person who was conscious of the earthquake. The papers of that city do not mention any local observation, though copiously publishing the dispatches from other parts of the country. At Carlisle, Huntington, and Tyrone no notice was taken of it. At Altoona it was felt very slightly by a few persons. But at Pittsburgh the swaying and tremulous motions were much more decided, and the proportion of the population which recognized it was quite large; and throughout the surrounding towns generally it was distinctly felt.

[Associated Press Dispatch.]

PITTSBURGH, *August* 31.

At 10 o'clock to-night an earthquake shock was felt in all parts of this city and Allegheny. The shock lasted about thirty seconds, and created the greatest consternation in the hotels and large buildings. In Hotel Anderson and Hotel Duquesne the guests ran into the streets panic-stricken, and in the upper stories of the Western Union Telegraph building the swaying of the structure was quite perceptible.

On the south side the shock seems to have been more severe. Dishes were thrown from shelves, clocks stopped, and the occupants of the houses rushed out screaming with terror. On South Nineteenth street the Lotus Club, which was holding a meeting, quickly adjourned, and the members, who were greatly frightened, lost no time in leaving the building.

Surrounding towns in all directions report a distinct vibration of the earth at about the same hour. As far as heard from there was no serious damage.

MEADVILLE, PA., *August* 31.

At 10 p. m. a shock of earthquake was felt, followed immediately by a slighter shock, the whole lasting about twenty seconds. The streets were at once filled with people. The guests rushed out of hotels in their night clothes, women and children were crying and screaming, and every one was more or less alarmed.

This comparative "earthquake shadow," which seems to pervade the greater portion of Pennsylvania, also appears to extend down the Appalachian region of West Virginia, though it is possible that this extension may be in great part apparent rather than real. The data from West Virginia are less copious than is to be desired; throughout the mountains of that State the population is scanty, and a part of it is, in respect to intelligence, much below the average of the country at large. An apparent defect of intensity seemed to disclose itself early in the investigation, and special efforts were made to multiply observations from this region; but though a considerable number were procured they were not wholly satisfactory. Taking the data at face value, the indications are that the intensity of the shocks varied extremely throughout the Appalachians of West Virginia; a few places giving an abormally high one; the great majority giving either a very feeble one or none at all. The inference, however, might have been very different if the State had possessed a population as dense and large towns as numerous as Ohio or Pennsylvania. In the capital of the State, Charleston, the vigor of the shocks was somewhat remarkable. The population is reported as having been thoroughly aroused by it and portions of the people alarmed. Some chimneys were overthrown, crockery broken, and houses forcibly rocked.

East of the Appalachians, in the Piedmont of Maryland and Virginia, the shocks were generally felt with a force which may be characterized as light to moderate. Nearly all towns give decided reports in the affirmative; a few report it as quite forcible and a few as not felt at all. In Baltimore and Washington it was generally felt. As regards the former city, the report of Mr. Richard Randolph, given in the chapter on the speed of the shocks (p. 176), may be taken as a standard. In Washington the tremors were very generally noted. Professor Newcomb's account is given in the same chapter as Mr. Richard Randolph's, and it may be well to introduce here the report given by Mr. W J McGee, of the Geological Survey:

The tremor was observed and correctly interpreted shortly after its commencement in Washington. The building 1424 Corcoran street is a brick structure, three

stories high, somewhat east of the center of a solid block extending about three-fourths the distance from Fourteenth to Fifteenth street, the houses being of variable depth. The room occupied was the upper front, facing north; the bed [occupied at the time the shock began] heads east, the head being two or three inches from the party-wall. A washstand with its accessories occupied the northeast corner of the room within reach of the bed; an office table stood near the northwest corner. On the table was a student-lamp, and above it a gas-fixture with globe. Over the headboard of the bed was thrown a leather belt, from which were suspended a heavy pistol and a hunting-knife. The tips of pistol and knife rested lightly against the headboard. The sensation conveyed by the first tremor produced the impression that some one had his hand on the foot of the bed and was shaking it to and fro; but knowing that the house had no other occupant, I quickly inferred the true cause of the disturbance. Meantime the violence of the shaking increased, and the points of pistol and knife began to rap against the headboard, and at the same time the movements of the bed were such as to indicate a quick eastward and upward impulse, as if the spring mattress were struck in an eastward and upward direction. At the same time also a rattling of the student lamp, of the globe on the gas-fixture, of the pitcher and basin on the washstand, and of the mirror on the dressing-case, together with some creaking of the bed and other articles of furniture, were perceived. I rose immediately, lighted the gas, and noted the time as 9.54½ [corrected to the 75th meridian standard]. As soon as possible thereafter the washstand was drawn toward the center of the room free from the wall, and a tumbler was nearly filled with water and placed upon it; and while waiting for the water to become still I gave attention to the swinging of the headboard of the bed and of the knife and pistol suspended from it. The headboard swung quite freely east and west. With each oscillation the suspended arms swung free from the headboard and then struck violently against it; and although the manner in which they were suspended permitted of free movement north and south, there was no tendency to swing in that direction. The undulations of the water in the glass corresponded closely in period with the swing of the headboard. Their direction was slightly north of east, and the successive waves rose higher on the eastward side of the glass.

In the Opera House on Fifteenth street the spectators in the upper gallery felt the swaying and were seized with such alarm that many of them rushed for the stairways. Although few people below felt the disturbance, the confusion above communicated alarm to the audience below, and for a few minutes a serious panic was impending. It was repressed, however, by the presence of mind of Mr. Sevellon A. Brown, the chief clerk of the State Department, who succeeded in arresting the attention of the audience, and assured them that there was no danger, unless the assemblage chose to create it by precipitating a panic. A few wise words bravely spoken recalled the spectators to their senses and perhaps averted a disaster. Some of them departed in safety, while others remained.

In Virginia, between the Potomac and the James Rivers, the shocks were universally felt, and the intensity rapidly increased southward. At Richmond they may be said to have become decidedly strong. The entire population of that city was thoroughly aroused, and a singular combination of circumstances produced an excitement out of proportion to the energy of the shocks, vigorous though they

were. The penitentiary, situated upon a high hill, was shaken with exceptional violence, and the prisoners were thrown into agonies of terror, converting the gloomy corridors and cells of the great building into a pandemonium. The keepers became alarmed, and, fearing a general jail delivery, called for help. In a short time police and military were hurrying to the rescue. A large part of the population, already alarmed by the earthquake, followed the troops, and the whole city was speedily in a state of panic and terror.

West of the Appalachians also the shocks were decidedly strong. In the upper Ohio Valley, from Pittsburgh as far as Catlettsburgh, the force of shocks varied from "moderate" to "strong." At Wellsville, Wheeling, Bellaire, Marietta, Parkersburgh, Barboursville, Huntington (W. Va.), and Catlettsburgh they were universally recognized, causing no little excitement and even alarm. Thus both east and west of the Appalachians of West Virginia the reports generally indicate a higher degree of intensity, and one more universally distributed than in the mountains themselves.

No State has given fuller or more satisfactory reports than Ohio. And there is hardly a town in it which did not feel the earthquake. As might be expected, it was more forcible in the southern parts than in the northern; but even in the northern parts it is rather a matter of surprise that they were so well marked. In Cleveland and in the surrounding towns and villages it appears to have displayed rather abnormal force.

[New York Times, September 1, 1886.]

CLEVELAND, OHIO, *August* 31.

A very strong shock of earthquake was felt here at 9.30 o'clock to-night, lasting perhaps fifteen seconds. People rushed out of their houses into the streets precipitately, the theaters were emptied, meetings were suddenly broken up, and a feeling akin to panic was general throughout the city, though no damage is reported. Everybody felt the nausea and dizziness which commonly accompany such shocks. The undulations were about east and west, and not less than three, though little definite testimony on that point is ascertainable on account of the unexpectedness of the phenomenon and the attendant excitement. Telegrams show that probably the whole State was shaken up.

The entire population were simultaneously seized with a sensation of dizziness and weakness, which was attributed to a sudden attack of illness, and the rocking motion plainly felt was at first ascribed to a deranged physical system. Houses were moved and everything within them. In some instances walls cracked with a startling noise, while in a few cases small fissures opened. A considerable number of people who were standing fell down. Persons on the ground felt light-headed, but many did not notice the undulations, though nearly every one had stomach qualms. The higher one was from the ground the greater was the motion. Everything hanging swung with violence, and the gas went out in some places and clocks stopped. In the Academy of Music a serio-comic singer had just begun his song when the audience as one man arose and scrambled out of doors, greatly to the performer's chagrin. A lodge of colored Odd Fellows was in the midst of initiating a candidate. The ceremony abruptly ended, and the entire body rushed down-stairs

in full regalia, leaving the candidate powerfully impressed. Billiard players were startled at observing the balls take most erratic courses. Not a few who had retired for the night were suddenly anxious for fresh air and terra firma. They neglected to arrange their toilets, and gave a ghostly appearance to their vicinity. The telephone exchanges were emptied of operators, and it was some minutes before subscribers could call one another. Then everybody wanted to call up somebody and inquire what the matter was. Many an amusing scene occurred in saloons, customers unceremoniously abandoning their waiting liquor and striding into the street. When all danger was past people compared notes and enjoyed the fun of the thing, but for a few moments the most intense and trying seriousness prevailed.

[New York Herald, September 1, 1886.]

CLEVELAND, *August* 31, 1886.

At thirty-three minutes past 9 to-night Cleveland was shaken by two distinct shocks of earthquake, lasting two seconds each, and giving all buildings and their contents a peculiar swaying sensation. Men sitting at their desks, of whom your correspondent was one, saw the paper before them sway and move. The shocks were very distinct, and were felt from one end of the town to the other, as well as at all the small towns in the northern part of the State from which reports have so far been received.

The occurrences created the wildest excitement on the down-town streets of Cleveland. Large audiences were in the Opera House and Academy of Music, and in a very few seconds the greater part of the people in them were out on the streets, comparing experiences, and watching the buildings, expecting them to fall. Various meetings were going on in halls and lodge-rooms. They were suddenly adjourned. Operators ran out of the big telegraph block, guests ran from the hotels, and in the residential portion of the city the people ran out of their houses trembling with fear.

These accounts are confirmed by private correspondence. Effects so pronounced at Cleveland are all the more remarkable, because on the other side of Lake Erie to Ontario they were noticed by very few people even in the largest towns.

All principal places on the line of the Pittsburgh, Fort Wayne and Chicago Railway and the places in proximity to it give accounts similar to those from Cleveland. Theaters, lodges, and prayer-meetings were broken up in confusion, high buildings were speedily abandoned, and nausea was universally complained of. Indeed the whole State of Ohio, except the northwestern corner, was shaken in much the same manner.

The accounts from Columbus are worth inserting. Thus Mr. H. R. Gill, of the railway station, sends a copy of the pencil memorandum he made at the time, and which is as follows:

9.21 p. m. city time [9.53 standard]. Earthquake. Motion apparently north and south. It has been vibrating for about one and three-quarter minutes. The cases are rattling and the telegraph wires under my window are vibrating as I never saw them before even in a severe storm. 9.27. More and more distinct vibrations. These appear to be exactly at right angles with the first. The chandelier in the telegraph office now swings due east and west. From the first to the last of the first set of vibrations was seventy-five to eighty seconds. This was determined by my watch, which was lying in front of me with correction. Second series did not last as long as the first.

The signal service observer, Sergt. A. L. McRae, reports that the severest shocks at Columbus were accompanied by a rumbling noise similar to that produced by a heavy wagon passing down the street; also that the shaking of the building in which his office was located was very strongly marked. He was writing at the time, and the tremors were great enough to distort the letters.

[Associated Press Dispatch.]

COLUMBUS, OHIO, *August* 31.

Reports are coming in from all over the city that a shock of an earthquake was distinctly felt about 8.54. It was more perceptible in large buildings. At the central Asylum for the Insane the furniture was turned around, and patients became so alarmed that the attendants had trouble in getting them to return to their wards. At the Institute for the Blind the shock was so strong that rocking-chairs on the floor were made to start in motion, and chandeliers were swayed to and fro with such force that they continued for sometime afterward in motion. These are samples of the sensation. The teachers at the blind institute refused to return to their rooms after running to the main audience room below. At this point it was accompanied by a low, heavy, rumbling sound. The time given at the Blind Institute was 9.22 local.

At Toledo, in the northwestern part of the State, it was noticed by many people, but was obviously less forcible than farther southward. In cities such as Mansfield, Dayton, Canton, Ironton, Xenia, Zanesville, Portsmouth, it was felt with an intensity varying from moderate to strong, and it is interesting to note the uniformity of character and detail pervading all these reports. Meetings of all kinds broke up in confusion, chandeliers swung, windows and small objects vibrated, and the oscillations of lofty buildings were often alarming. There is hardly a town in the southwestern quarter of the State which does not report an epidemic of nausea experienced in many cases by people who had no idea of an earthquake, and who attributed it to some sudden and passing qualm of the stomach, or to some peculiar dizziness, or to some defective action of the heart, according to the infirmity of the patient. Although the observation of an earthquake a day after its occurrence, and when the fame of it has been widely trumpeted, is generally of doubtful value, these universal and widespread reports of nausea are much too artless to be doubted. Assuredly this must indicate the passage of normal waves of great wave length and correspondingly long period, but of small amplitude.

The city of Cincinnati and its surburban towns have given many reports. In the upper stories of large buildings it created general excitement and often considerable alarm, while upon the sidewalks and pavements it was not generally observed. It was of sufficient force to break up many meetings and to stop many clocks, to rattle window-weights and windows, to awaken some sleepers, and in sensitive localities to produce considerable confusion. From this city and its neighborhood come an unusually large number of good time reports.

In the State of Indiana the intensity was clearly less than in Ohio. In the latter State it is rare to find a town or village, however small, that was not aroused by the shocks, excepting in the northwestern part of the State; but in Indiana a large number of places return negative reports. Nearly all of the large towns, however, were perceptibly affected and some of them strongly so. In Indianapolis it was generally observed by persons favorably situated, but was unnoticed by many. As usual, the occupants of higher rooms perceived it both as a continuous tremor and a regular oscillation. At one of the rooms considerable confusion was created among the guests, and a large coping stone, probably not fast in its place, was shaken down upon the pavement below. In the tower of the court-house the swaying was so great as to terrify the watchman, who escaped in alarm. The great clock in this tower was stopped. At Evansville, on the Ohio River, the vibration was marked and was noted by a large number of persons. In the southeastern part of the State it rarely failed to make itself felt decidedly, and nearly all of the localities heard from in that quarter give positive answers. In the northwestern quarter the reverse is the case. Few localities give a positive reply, and the majority are negative. At Terre Haute, in the western part of the State, the shaking seems to have been abnormally great. A panic was created by it in the Opera House, and it seems to have been felt very decidedly by a large portion of the population. It was noted in high buildings, as usual, much more decidedly than in low ones.

In southwestern Indiana and southeastern Illinois is a considerable region where the reports indicate a defect of intensity. All around this locality, in southwestern and central Illinois, in western Kentucky, and southeastern Indiana, the reports of well-marked vibrations are very general. In the defective tract few localities give any indication of them. This defect was observed early in the course of the investigation, and in order to ascertain whether it were real or only apparent, special investigation was made, with the result that the earthquake was certainly less forcible there than in surrounding regions. Such earthquake "shadows" are by no means uncommon. Their causes can only be conjectured. Another earthquake shadow seemed to be indicated in the northern part of Illinois. Here there is more room for question. This part of the State is very remote from the center of disturbance; vibrations would necessarily be very feeble, and it is in no way surprising that large tracts should give no indications of it near the limits of sensibility. On the other hand, there were several places in Illinois where it was felt with a force that seems somewhat abnormal. Thus at Murphysborough the shock is reported as exceptionally severe. Glassware was rattled, doors and windows vibrated strongly, the fire bell in the court-house was rung, hanging lamps oscillated, and a lodge meeting in a second-story room was panic stricken, the members rushing in dismay into the street.

Many people also complained of nausea. There were said to be two shocks, each lasting more than a minute.

In Chicago the shocks were felt very forcibly in lofty buildings, but in the lower stories very few people observed it at all. It may be of interest to reproduce the reports given in the Chicago papers.

[Chicago Herald and Inter-Ocean.]

In Chicago the shock was felt about 9 o'clock, city time, the vibration being especially noticeable in the upper stories of the larger and taller buildings. People on the streets and on the lower floors do not seem to have noticed the shock.

At the Leland Hotel guests on the upper floors became so alarmed that they left their rooms and ran into the adjoining halls in consternation. Men and women, some of them only partially clothed, looked at each other in amazement and terror, as if they expected that their stay on earth was to be summarily terminated. Under the intense excitement of the moment several ladies became hysterical and refused to again return to their rooms. The sensation exper enced is described variously. Some liken the feeling to seasickness, and say they were filled with horror at what they could not explain. One guest said: "I seemed to suddenly lose myself, as if I were about to faint, and when a rocking-chair moved and different objects in the room swayed back and forth I didn't know but the whole establishment was about to collapse. It lasted fully half a minute, the building rocking gently all the time." It required the best arguments of attendants in the house to induce the guests to again enter their rooms, which they did only after nearly a half hour had elapsed and they felt reasonably sure that the peculiar phenomenon would not again manifest itself.

The reading-room of the Public Library, on the fourth floor of the City Hall, is in a large gallery, suspended from the ceiling. About forty people sat at the tables, interested in the various periodicals, when the whole gallery swayed to and fro under the motion of the terrestrial disturbance. Papers and magazines were thrown hurriedly down and the people scrambled out of their perch and downstairs in pell-mell order. The shock was not perceptible in the other parts of the City Hall.

In the Richelieu the shock was slightly felt. The Beaurivage apartment building was shaken up in that part above the fourth floor, the plastering being shaken from the walls and ceiling in several of the rooms.

The earthquake was very perceptibly felt on the ninth floor of the Pullman building. In the café the glass and china ware was jingled up with a great clatter, but there was no damage done.

At the Commercial Hotel the shock was plainly felt.

The shock was distinctly noticed in the Major Block, at the corner of LaSalle and Madison streets and its vicinity. The janitor of the Major Block and his family were eating supper, when the dishes rattled on the tables and the walls of the building trembled. The family ran out of the room in alarm, thinking that another explosion had occurred, or that the building was going to fall. They mentioned the fact to the signal service observer, who is in the same building, and he explained that it was a slight earthquake.

Judge Prendergast was sitting in his parlor at No. 534 West Jackson street a few minutes before 9 o'clock, and he felt the house shaking. The motion was quite violent, and the judge thought the house was about to tumble. The shaking ceased as suddenly as it began.

Several persons who were in Clancey's drug store, at No. 525 Van Buren street, felt the shock also, and one woman rushed out of the store very much frightened.

The shock was distinctly felt in all parts of this city and in many other neigh-

boring cities. W. W. Leffingwell, the manager of the central telephone station, was besieged for an hour after the event by persons anxious to know what caused the shock. No special damage was reported.

"I was sitting at my desk watching the boys," said Mr. Leffingwell, "when I felt the swaying motion. The blinds moved slightly, and some of the pegs in the connecting apparatus fell out of place. The boys who were on their feet and walking around did not feel the motion at all. Evanston people were quite badly scared by it. It must have been a good deal stronger up there, as they say that chairs were moved in the first floors of buildings. Out at Elgin no one knew that there had been a shock, though the Milwaukee folks were fully alive to the fact."

At the Tremont House the shock was marked. W. H. Shaffer, the night clerk, who at the time was asleep in the upper story, was aroused by the moving of his bed. Guests ran from their rooms, and for a time were badly frightened. No damage was discovered, with the exception of the cracking of a large glass skylight.

Throughout the State of Kentucky the earthquake exhibited considerable force. In the eastern part of this State it was decidedly strong. The mountainous character of eastern Kentucky, its scanty population, and the lack of large towns rendered it somewhat difficult to obtain full reports, but special effort to procure them was attended with success, and the indications which they give are decisive. The energy of the shocks in that region was great, ranging from strong to severe. They were forcible enough to crack walls and overthrow chimneys, always creating alarm and sometimes terror. The intensity in eastern Kentucky appears to have exceeded what might have been expected there. Westward in the same State the energy exhibited a steady diminution. In the central portion, while sometimes strong and always moderate, it was obviously much less forcible than in the eastern portion. In the western part of the State the intensity showed much enfeeblement, and although quite sensible near the Mississippi River, it vanished about a hundred miles to the west of it. It will be of interest here to note the intensity in the southeastern part of Missouri, in the vicinity of New Madrid, which was in the epicentral tract of the great earthquakes of 1811–'12. We shall thus be enabled to make some comparison between these two great earthquakes.

Let us first recall the effects of the New Madrid earthquake in Charleston. A careful comparison of the accounts preserved indicate that they were as violent at least as that of the Charleston earthquake in Atlanta, Asheville, Raleigh, and Wilmington. The accounts given by localities situated about two hundred miles from Charleston approximate very closely the indicated intensity of the New Madrid earthquake in Charleston. The distance between the epicentra of the two earthquakes is about six hundred miles. At New Madrid the Charleston earthquake was felt only as a very feeble tremor, noticed indeed by a number of persons, but exciting no comments at the time, because such tremors are felt there rather frequently. It will thus be seen that the New Madrid earthquake was a convulsion vastly exceeding that of Charleston.

The effects in Tennessee were very similar to those in Kentucky. The eastern part of the State was very forcibly shaken, and every town in that region was aroused by it. At Knoxville the alarm was general. Many walls were slightly cracked, window glasses broken, furniture moved, meetings ended in a panic, and the population thrown into a state of excitement sometimes amounting to alarm and terror. Reports from surrounding towns in East Tennessee give indications of equal violence. In the central part of the State the vigor of the shocks was also considerable.

[Nashville Daily Chronicle.]

In the Chronicle office (Nashville), third floor, walls and floors shook, windows rattled, and a sensation like seasickness was caused. The entire force in the printing office made a rush for the stairway and ran out of doors. From every building, as far as the eye could reach, people were running for safety out into the middle of the street. There were three distinct shocks: the first at 8.55, lasting possibly 40 seconds; the second at 9.03, and the third at 9.09; the last two of 30 seconds duration each, and they were barely felt. The first shock might be termed violent. The first sensation was a slight quiver, which grew in violence until the walls of the building rocked to and fro. There also seemed to be a feeling of a vibratory motion, as if the shock were made up of several distinct waves. No damage was done beyond the breaking of a few panes of glass and the cracking of plastering.

Numerous towns surrounding Nashville give reports indicating a similar intensity. In the western part of the State the force of the tremors, though notably less, seem to have been remarkably well sustained. At Memphis, on the Mississippi River, they were strongly marked, attracting almost universal attention. A very interesting account has been given by Sergeant D. T. Flannery, of the Signal Service, stationed at Memphis, from which it appears that few people in that city failed to observe and recognize the shocks. The intensity was sufficient to stop many clocks, to start two clocks which were previously at rest, and to retard 13 seconds the standard clock which controls the time of the city. Suspended objects were made to swing, windows and doors were rattled, rocking-chairs set in motion, and very sensible vibrations communicated to beds on which persons were lying. The oscillation of buildings was almost universal, and was felt not only in upper stories, where it was much more forcible, but frequently in the lower ones. Meetings were broken up in confusion and the occupants of many buildings ran hastily into the streets. The manifestations at Memphis seem abnormally great when the distance from the origin is considered. Surrounding towns, however, indicate an intensity not appreciably different.

Crossing the Mississippi into Arkansas, we find the intensity fading out with rapidity to the westward. A few localities in the northeastern part of that State give positive reports, but many of

them give negative ones, and in the central part of Arkansas it does not appear to have been recognized at all.

Alabama was everywhere shaken, but with an energy which may range from "light" in the southern part of the State to "strong" in the northeastern part. Throughout the greater part of it the intensity was about normal, though in the southwestern portion the indications suggest somewhat less than the normal. Here begins to show itself that tendency, already referred to, of the isoseismal lines to crowd together in a southwesterly direction. It is shown most clearly in the State of Mississippi. The delta deposits of the river are of great thickness in the southern part of that State, and as they are not well suited for the transmission of the elastic impulses of the earthquake, they were expected to show a great defect in the energy. This is clearly the case. Very few places in southern Mississippi return affirmative reports, though in the northern part of the State the intensity appears to have been quite normal. In Louisiana two places only have given affirmative reports, one being the Rigollets light-house, where it was betrayed by the swaying of the tall tower; the other New Orleans, where a very few persons in a large city recognized the tremors and identified them. We may believe that the waves were propagated in the profounder depths and among the more solid rocks beneath this region without any sensible loss of energy; but in passing through so great a thickness of unconsolidated or imperfectly consolidated material as that which constitutes the Mississippi Delta, the extinction of a large part of the energy is to be expected. It is a repetition of the fact presented along the Atlantic coast both north and south of Charleston, though exemplified here upon a somewhat broader area.

The foregoing abstract of the effects of the earthquake throughout the country at large deals only with the distribution of intensity. The direction of motion is studiously ignored. Without means of determining the actual motion of any point upon the ground, it has been deemed useless to encumber the record with the various statements made in the reports as to the directions inferred. We know now that these motions are in every direction, and that a house or other structure is set vibrating in whatsoever direction its elastic yielding is greatest; in other words, the direction of oscillation depends upon the structure itself and not upon the direction of the passing wave. It is only in localities within and near the epicentral tract of a great earthquake that indications of direction (other than those obtained by good seismographs) are of much utility or instruction.

Neither has any particular mention been made of the duration of the shocks. This is a matter of much more interest and importance. But the reports are so uncertain, the observations of duration so poorly made in almost all of the cases, that it has been deemed best not to attempt to extract anything from them in this chapter.

## CHAPTER VI.

### THE ISOSEISMALS.

The study of the isoseismals has involved a very large amount of labor and has yielded a very small result. Much was hoped from the vast number of reports obtained from all parts of the country, but the hope has been in great part disappointed. The reasons are soon stated. In the absence of good instrumental measurements of the motions of the ground during an earthquake we have no resource but to infer relative intensities from the effects of the shaking upon structures and natural objects, and upon the sensations and emotions of persons. If we could reach just estimates of these effects no doubt much would be gained by comparing large numbers of them with each other. But this is difficult to attain, because the persons who make the reports differ widely in temperament and in judgment; very few of them are skilled observers, and fewer still ever before experienced a forcible earthquake. Hence a majority of the reports are much impaired by the imperfections of the observations. A large number of them are derived from newspapers. But the American newspaper reporters frequently consider it for the interest of the journals they serve to tincture their accounts with two qualities: first, the sensational; second, the funny. This habit may or may not promote the interests of journalism. It does not help the scientific investigation of an earthquake. There are certainly many gratifying exceptions to the general rule. Some of the accounts, especially those given by the press associations, were written with calmness, sincerity, and dignity, and bear internal evidence of sincere efforts to state whatever facts were noted with exactitude and candor. The greatest defect of such reports is a negative one; they seldom state that the earthquake was *not* felt where it might have been expected to be sensible. Confining themselves to statements of the most striking results and silent about everything else, they are apt to leave the impression that these emphatic manifestations are typical or representative, while in reality they are exceptional, and unless caution is exercised by the investigator are also misleading. It is as interesting and quite as important to know what the earthquake failed to do as to know what it did.

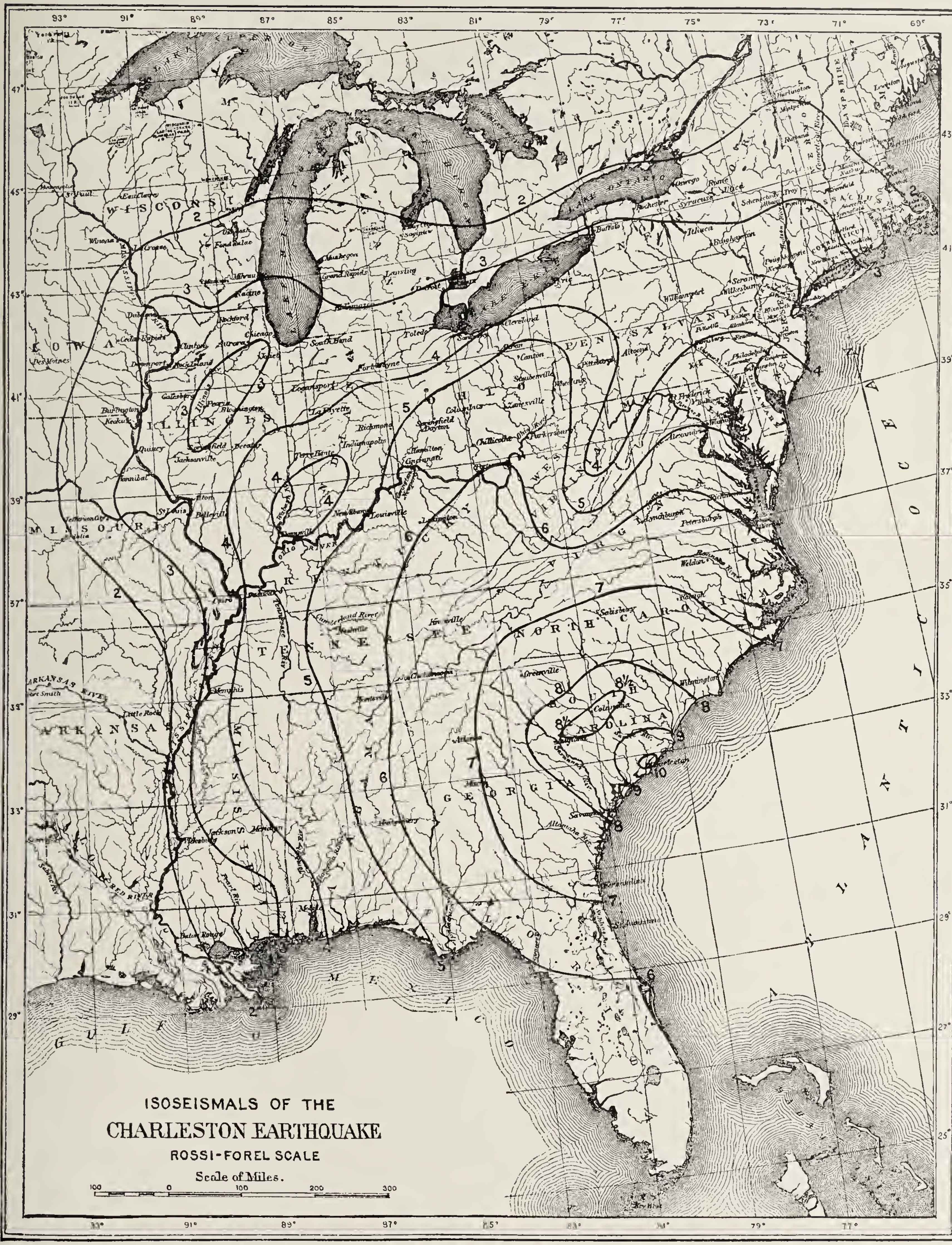
Another difficulty arises from the want of any rational standard of comparison between the different degrees of intensity. For example, how much greater in terms of energy, or of any other unit of measure, is an intensity which will crack brick walls and overthrow

chimneys than an intensity which will merely dislodge some loose plastering, ring a few house bells, rattle windows, and perhaps alarm a negro prayer-meeting. Undoubtedly after reading two such accounts the reader will be impressed with the conviction that there was a decided difference ; but he will have no means of judging how great that difference may have been. In the current practice of estimating intensities there is no established unit, and there cannot, consequently, be any definite comparison between them. It is presumed of course that there is some conceivable unit of energy, but it has not been possible hitherto to employ any such unit as a measure of those indications of energy which we are compelled to rely upon in forming our provisional and arbitrary estimates. All that we can gather from the isoseismals therefore is the mere fact that in certain places the intensity was greater than in others or less than in some third series of places; how much we can not say.

In selecting a scale of intensity based upon the sensible effects of the earthquake the Rossi-Forel scale was finally chosen. The first series of circulars distributed immediately after the earthquake embraced a scale established by Prof. C. G. Rockwood, containing only five degrees of intensity. It was found, however, that in most cases it was possible to distinguish, with a fair degree of confidence, intermediate degrees of intensity, and as the Rossi-Forel scale ranged through ten degrees, it was thought best to employ it in all subsequent circulars, and also to re-estimate the intensities given in the Rockwood scale in conformity with Rossi-Forel. This re-estimate was found to be quite practicable in most cases. It was not, however, free from difficulty, and one of a curious kind is worth recording. After estimating some hundreds of reports, I found to my surprise that my own subjective standard (I can think of no other term to characterize it) had undergone a gradual change. Effects which were adjudged to indicate an intensity of four or five in the earlier stages of the process were later on adjudged to indicate a lower and lower intensity. This necessitated beginning the process over again. In spite of precautions the same defect repeated itself. It was not until the fourth or fifth trial that this unsteadiness of the mental machine could be prevented.

Pl. XXIX exhibits the isoseismals. Probably no two persons taking the same data independently would draw exactly similar lines. Nevertheless it is believed that all of the principal features of the drawing here given would appear in one form or another if a similar work were undertaken by any other person.

It is to the irregularites of these lines that we must look for instruction or suggestion. But they suggest little. Several areas of earthquake shadow are indicated, of which perhaps the most notable is in West Virginia. A closer grouping of the isoseismals along the coast than in the interior also appears, the explanation of which




ISOSEISMALS THROUGHOUT THE COUNTRY.

has already been proposed. It will be perceived that the intervals between isoseismals is not very unequal from the epicentrum to the remotest points of sensibility. If this be a true representation of the variation of intensity, and if the intervals between any two correspond to a difference of intensity equal for all intervals, then it would follow that the intensity was, on the average, inversely proportional to the distance in a simple reciprocal ratio. But according to universal laws governing all radient energy or energy moving away from a center, it should diminish as the *square* of the distance increases, provided no energy is dissipated in the transmission. But if energy be dissipated, the rate of diminution must be still greater. Here is suggested at once the need of a much more definite understanding as to the relative degrees of intensity the several isoseismals ought to express. As the case now stands there is no assignable relation of one isoseismal to another. To ascertain what relations they might express we must have recourse to theory.

Let us revert to the intensity curve which was deduced in Chapter IV. Only that portion of the curve was there used which applied to intensities in the epicentral tract and its vicinity. It has two symmetrical branches, extending to infinity in both directions, and the axis of abscissas is an asymptote to both branches. We are to consider how the intensities at different distances would compare with each other on the assumption that no energy is lost in the transmission.

The following table will show the ratio of the intensity at distant points to that at the epicentrum, on the assumption that the depth of the focus is 12 miles:

| Distance from epicentrum. | Ratio of intensity. | Ratio of amplitude. | Distance from epicentrum. | Ratio of intensity. | Ratio of amplitude. |
|---|---|---|---|---|---|
| *Miles.* | | | *Miles.* | | |
| 12 | .5 | .7 | 300 | .0016 | .04 |
| 24 | .2 | .447 | 400 | .0009 | .03 |
| 36 | .1 | .316 | 500 | .00058 | .024 |
| 48 | .0588 | .242 | 600 | .00040 | .020 |
| 60 | .0389 | .197 | 700 | .00029 | .017 |
| 72 | .027 | .164 | 800 | .000225 | .015 |
| 84 | .020 | .141 | 900 | .000178 | .0133 |
| 96 | .0156 | .125 | 1,000 | .000144 | .0120 |
| 100 | .0142 | .119 | 1,100 | .000119 | .0109 |
| 200 | .0036 | .06 | 1,200 | .0001 | .01 |

From this it will appear that the differences of intensity between the outer isoseismals are very small, while those between the inner isoseismals are many times greater. If our estimate of the depth of the focus is correct, then the intensity at the most distant points at which the earthquake was felt must have been less than the six-thou

sandth part of the intensity at the epicentrum. Even this enormous difference makes no allowance for any loss of energy in transit, which must correspondingly magnify the disproportion. It is evident that without accurate measurements of intensity and a large number of them the outer isoseismals can convey but little meaning. But an important question may be raised here. Is it not possible that the intensity of every earthquake may be considered as approximately the same at the extreme distances at which it is felt? If this were true we should then have one ordinate for the intensity curve of every earthquake, and if we could determine the depth, or could determine one other ordinate, we should be able to find the whole curve, and thus compare all earthquakes with each other. The answer to this question is so qualified as to be of little value at present. It will appear in the following chapter that when different waves are compared the effects they produce are dependent not wholly upon their intensity (which will be defined to be the amount of energy per unit area of wave front); but with equal energies the effects will differ with the varying periods, wave lengths, and amplitudes, in such a way that no exact comparison is possible until we know all these factors which go collectively to make up the intensity. Furthermore, the intensity of a single wave may be great and yet produce a smaller perceptible effect than the cumulative result of a considerable number of waves each of much smaller intensity. Thus the duration of the shocks may, and in most cases probably does, constitute an important factor. And, finally, we do not know what proportion of the energy is lost in the propagation of the waves. This loss of energy must modify the fundamental law of variation of intensity with the distance which we are here assuming.

Notwithstanding these difficulties, all of which must qualify our conclusions, it is believed that they may possibly be insufficient to wholly vitiate them and to render them absolutely worthless. It certainly seems as if the smallest intensities which seismoscopes of uniform pattern would record upon the outermost isoseismals may represent energies in different earthquakes which are not very unequal. If this be so, then the mean distance of such an isoseismal from the origin would become a measure of the total energy of the earthquake, not however in absolute, but in relative, terms. The total energy would in that case be proportional to the square of the greatest distance at which such an intensity was manifested. If we can determine any two ordinates of the intensity curve, or one ordinate and the depth of the focus, we can determine the entire curve.

These considerations suggest a method by which we may seek to establish some system of isoseismals which will be more rational than the arbitrary one now in general use. By the present method the isoseismals express the wall-cracking power, the chimney-breaking power, the man-frightening power, etc. They really express

very little of what we wish to know. Although they indicate that one area was more forcibly shaken than another, they do not convey the remotest idea *how much* more forcibly. What we really want is a system which will express graphically the ratio which the energy displayed in one region bears to that displayed in another in terms of some unit of energy. I believe such a system may in future become possible, though I concede the present difficulty of procuring the data for it. The mathematical theory upon which it may be founded is soon stated. Its practical exemplification must be a matter of future research.

A system of isoseismals as here contemplated would express the relation between two variables, viz: (1) the distance from the epicentrum and (2) the intensity, or some function of the intensity, measured in units of energy. The independent variable must obviously be the distance from the epicentrum; the function must be the intensity. For every observation a map and a scale gives us the distance. It remains to measure the intensity. The only possible source of information at present available for this purpose is the seismograph. It measures amplitudes and wave periods. If we also know either the wave speed or the wave length the record would be complete. Here is a serious difficulty at once. Although the Charleston earthquake has probably settled the first near approximation to the true speed of a deeply seated wave, it does not affect the question of the speed of those transformed surface vibrations which the seismograph measures. We may hope however, as the result of such experiments as those begun by Mallet and prosecuted by Ewing and Milne in Japan and by Fouqué and Michel-Levy in France, to ascertain something more definite about wave speeds in the surface soils and in different kinds of rocky strata near the earth's surface.

There is another difficulty to be met, viz: the fact that amplitude and wave period both vary in closely adjoining localities. These differences are due presumably to surface conditions, *i. e.*, to the kind of rock or soil which constitute the superficial masses. Time and experience, however, with multiplied observations, may enable us to judge what allowance must be made for such perturbations. In the long run and with many observations such discordances may be treated as accidental errors, which may be in greatest part eliminated.

The question as to the dissipation of energy in transmission is one which may be disposed of with little comment. The proportion of energy so lost is probably small in the depths of the earth. Whatever portion reaches the surface is probably almost wholly dissipated there, very little of it being reflected back into the earth. Taking an analogy from light, the case, so far as regards reflection, is probably analogous to that of rays passing through a transparent medium and falling at its boundary upon a rough black surface.

The foregoing considerations may be of utility in determining

future methods of observing earthquake phenomena. They indicate the importance of establishing a large number of seismoscopes, or instruments for merely noting the fact of a tremor of an intensity not less than some definite degree and the time of its occurrence; secondly, a moderate number of seismographs located in carefully selected places and in groups, which may give indications of amplitude and wave period. The first class of instruments are cheap and simple; the second, costly and elaborate. Both may be necessary to the complete scientific investigation of the earthquake.

## CHAPTER VII.

### THE SPEED OF THE SHOCKS.

At the time of the earthquake there was not within the United States a single seismoscope or other suitable instrument of precision on guard and so connected with a clock as to give an accurate record of the time at which the impulses arrived. Nevertheless there were several circumstances which gave hope that a fairly satisfactory result might be reached. In the first place, the shocks had been felt throughont a vast extent of country and were observed nearly a thousand miles from their origin, thus giving us a long "base line," so to speak. Within this great disturbed tract resided nearly forty millions of civilized people, provided abundantly with clocks and watches, with newspapers, telegraphs, and railways. But, above all, the fact which gave the highest encouragement was the existence and successful working of the *standard time system*, whereby once each day a signal is telegraphed from an astronomical clock to every telegraph station in the country at an appointed hour, minute, and second. Thus every village reached by a telegraph line has the means of knowing each day the time of some standard meridian to a single second. Even in places not so reached (and they are few and small in importance) the means of almost equal accuracy are generally provided. The stage-driver who carries the mail or the postboy who crams the mail into his saddlebags sets his watch at the railway station with all practicable accuracy before he starts, knowing that some farmer along the wayside or some of the villagers whose doors he passes will demand the exact time.

The difficulty and confusion which would inevitably have arisen if the time-keeping of the country were "local" instead of "standard" would have proved insuperable. It is quite true that local time is still kept in some parts of the country; but so far has this been from a disadvantage, that on the whole, for our present purposes, it has been an advantage. Districts which keep local time keep standard time also, and the latter has almost revolutionized the former, making accurate and systematic what was before loose and unsystematic. Between the 80th and 85th meridians the local time of some neighboring city or large town is found to be more convenient for most purposes than standard time. Thus around Pittsburgh

many towns keep the local mean time of the Allegheny Observatory, which is $20^m\ 3^s$ west of the 75th meridian. They also have the standard time of that meridian, and deduct 20 minutes to obtain their local time. Towns in the vicinity of Columbus, Ohio, and as far south of that city as the Ohio River, use the local time of Columbus, but not that of their own localities. The correction to the time of the 75th meridian is almost exactly 32 minutes. Thus every intelligent man in such places knows that he must add a certain number of minutes to his local time to get the time of the railroad. The result is that local time-keeping, wherever it still prevails, has been enormously improved by the superposition of the standard system. The latter does not exclude the former, but helps and strengthens it.

It was not anticipated that one person in a hundred would note the time, nor that more than a very small percentage of those who did note it would send their observations to this office. But, in order that as many observations as possible should be secured, the notices published in the newspapers, through the courtesy of the Associated Press, requested all persons who had made such observations to forward them to the Director of the Geological Survey. Many persons did so. The Chief Signal Officer instructed the observers of his bureau who had noted the time of the shock to report it, and he placed all their reports at the service of the Survey.

The Western Union Telegraph Company, at my request, instructed its operators to forward similar reports, and the Light-House Board sent a special circular of instructions to all its light-keepers to send replies to the formal inquiries promulgated from this office and furnished copies of them. Special effort was made to secure newspapers from as many localities as possible. Most of the leading papers of the country have an agent or reporter at Washington, who usually keeps a file of the paper he serves. The Library of Congress keeps files of two or more newspapers from every State. As many of these as practicable were thoroughly examined. A large number of local papers were requested to furnish copies of their issues of September 1, 2, and 3, and they complied. Many marked copies of newspapers were sent to the Survey voluntarily from unexpected sources. Altogether more than four hundred time reports were gathered from the various sources.

Necessarily a large proportion of these reports were useless. In order that it may be apparent what reports were selected for consideration, and what ones were rejected and why they were rejected, the following account is given. Many of them stated that the shock occurred "about half past 9," or "about 10 o'clock," or "a few minutes before 10." A single minute is a large quantity in this relation, and as such reports involve an uncertainty which is probably much greater than one, or even than two, minutes, they were summarily

rejected. But when the report stated that it occurred "at 10 o'clock," without any qualification, it was taken into the first consideration, though rejected upon the second. The reports from light-houses generally proved unavailable. These structures, being situated frequently in localities where access to standard time is very difficult, they regulate their clocks by the sun and an almanac. The uncertainties of this method of time-keeping amount to several minutes, and are too great to justify their acceptance. A few light-houses are within reach of standard time, and are governed by it. From these a few very good reports have been received. There were also a few which differed so widely from the great majority of reports that they were thrown out at once as involving unexplained errors of great magnitude—ten minutes or more. The number omitted from the first list for this reason was only nine.

As fast as the reports were received they were scrutinized. Those which bore internal evidence that they were carefully made by persons who had the means of knowing the time with accuracy became the subject of special correspondence. Others, which were apparently good in some respects but defective in one or two, were followed up with further inquiry, in the hope that more information would cure the defects. In only a few cases was this hope realized.

The number of time reports gleaned from the newspapers was very large, and though subject to one difficulty, which will be mentioned speedily, they proved to be better than was at first anticipated. It is the custom of newspaper reporters to state the time at which any event described by them occurred. Ordinarily this time is stated rather roughly as occurring at or about some particular hour or half hour. But the reporter's calling demands of him the greatest punctuality in some things, and whenever accuracy of specification in matters of time is an important point he is as quick to recognize this requirement as any one who is not specially expert in such matters. The great majority of newspaper reports bear internal evidence that they endeavor to give the nearest minute of the principal shock. In the papers published in the large cities or towns and having a large circulation there is little trace of the widely prevalent tendency to consider the nearest five minutes near enough for all practical purposes. There is, however, the following difficulty: these papers give special dispatches from smaller outlying towns, where this tendency plainly appears. They come to the papers from occasional correspondents less active and less clever at their business than the keen, hawk-eyed, omnipresent regulars of the city office. These "specials" from outlying towns are in many cases strongly affected by the five-minute tendency. But there are also many of them which give the observed minute. All these reports are obviously liable to the error of the time-piece. But this is an "accidental

error" which, if the number of observations be great enough, can be eliminated.

While the work of collecting general data relating to the earthquake was in progress it was thought best to place the time reports in other hands, in order to expedite the discussion and hasten the completion of the monograph. Prof. Simon Newcomb was therefore requested to discuss the time data, and he consented. A list of such observations as had then been collected was made and sent to him. His preliminary examination led him to entertain a poor opinion of the data as a whole; an opinion which he subsequently modified greatly. There were two observations, however, which he regarded as having claims to accuracy much exceeding any others. One of these was his own, an account of which is given farther on, and the other was the automatic record made by the magnetograph of the Canada Meteorological Service at Toronto. In addition to this, the time at Charleston was known with considerable precision, the time first accepted by Professor Newcomb being 9.51, which proved to be within six seconds of the time finally accepted after a most careful scrutiny. Professor Newcomb's own observation undoubtedly deserved the confidence he placed in it. A judgment of the value of the Toronto observation can be formed best by reading Professor Newcomb's discussion of it, which is given in an appendix.

Subsequently he made a more careful examination of the other observations, which he determined to subject to equations of condition. The result proved to be better than he had hoped. In the meantime further investigation had brought to light additional time data and more rigid scrutiny had furnished the means of assigning better weights to such as were already in hand, and had also indicated clearly that some should be rejected which had been accepted. As this examination involved more labor than Professor Newcomb had time to devote to it, I resolved to take up the subject and discuss it thoroughly, profiting largely by the work which he had already done, and following so far as practicable the methods which he had selected, but making a much more rigorous classification of the data, and endeavoring to eliminate certain systematic errors whose existence in Professor Newcomb's result seemed to be manifest. Four months of very diligent labor were spent in the scrutiny of the data and in subjecting them to equations of condition. I will now proceed to set forth in their regular order the method employed of treating the data, their arrangement, the process of sifting them, their final grouping after the rejection of inadmissible observations, and their results when subjected to equations of condition.

By far the most important time to be determined is the beginning of the powerful shocks at Charleston. An error here of a very few seconds must cause a considerable uncertainty in the result, while an

equal error in any other locality would be of much less consequence. It was not to be expected that any good personal observation of the time would be made under such appalling circumstances. And yet I must advert to the uncorrected observation of Mr. F. R. Fisher, already given (p. 243). Unfortunately this observation is not available for present purposes. The principal means of determining the time at Charleston consists in the stopped clocks. If it were the only means our result would have a much greater uncertainty than is desirable; for investigation shows that a delicate clock may go through a violent earthquake without stopping at all, or it may stop at any time during the height of the convulsion, or it may stop at the first and faintest tremor. The regulator in a jewelry store, No. 251 King street, in Charleston, did not stop at all. At Rome, Ga., a fine clock, well regulated, passed through the great shock, but stopped at the lighter one, which came about five minutes later. At Manistee, Mich., 855 miles distant, and where the tremors must have been exceedingly feeble, though sensible, the pendulum of a clock, after beating against its case for nearly a minute, at length ceased to vibrate. Several cases are reported where clocks kept in motion through the greater shocks, but stopped at the milder subsequent ones. The uncertainty of stopped clocks will appear more fully when we come to treat specially of that part of the subject. In Charleston, however, the earthquake arrested nearly all the clocks in the city as soon as it reached a high degree of energy, and probably arrested some of them in the earliest phases and before that energy had risen to the first maximum.

There were four stopped clocks whose errors up to the moment of arrest were probably only a very few seconds. The first of these was the regulator of James Allan & Co., No. 285 King street. It is regulated by means of a sounder, which is daily put into circuit with the Western Union's time-signal wire. The clock is corrected only when its cumulative error exceeds nine seconds; but its error on the day in question was not known beyond the fact that it did not exceed nine seconds. Mr. Allan is authority for the statement that its reading the next morning was $9^h\ 51^m$ exactly. The second clock was a fine large regulator, with a heavy seconds pendulum, in the station of the Northeastern Railway. This clock also was regulated by the noon signal, received by telegraph at the station. It had not been set for two days, as its error on August 31 was less than eight seconds, which was the limit of tolerance. It stopped, according to Mr. Earle Sloan, at $9^h\ 51^m\ 15^s$, the point of the pendulum having been caught behind the arc, in front of which it properly oscillates. The third clock was the regulator of the Charleston and Savannah Railway. It was compared with the time signal on August 31, but was not corrected, as it would have been if its error had exceeded eight seconds. Its reading was ascertained by Mr. Earle Sloan a few days after the

shock to have been $9^h\ 51^m\ 16^s$, almost exactly the same as the preceding. The fourth clock was that of the South Carolina Railway. It had been compared that day with the time signal, and, its error being greater than the tolerance, it was reset to the second. Its reading is given by Mr. Sloan at $9^h\ 51^m\ 48^s$.

The comparatively wide discrepancy of these readings looks at first somewhat discouraging. They range through an interval of forty-eight seconds. But the reading of the last clock—$9^h\ 51^m\ 48^s$—must be inquired into a little further. The azimuths of the planes of oscillation of their pendulums are as follows:

| | |
|---|---|
| James Allan & Co. | N. 85° E. |
| Northeastern Railroad | N. 40° E. |
| Charleston and Savannah Railway | N. 66° E. |
| South Carolina Railway | N. 30° W. |

Hence the planes of oscillation of the first three made very wide angles with the direction of the normal impulses, which came first from the main centrum, situated N. 30° W. of Charleston; while the plane of oscillation of the last clock coincided with it as nearly as possible. Hence the first three clocks ought presumably to have stopped in the first maximum, or near it, while the fourth may easily have gone on until affected by the impulses of the second maximum, which came about thirty or forty seconds later, and were almost at right angles with the earlier ones. The facts are very favorable to the presumption that the last clock was stopped by the second maximum, and if we allow thirty-five seconds for the interval between the two maxima, the correction would place it in close agreement with the other two railroad clocks. This still leaves a difference of fifteen seconds between James Allan & Co.'s clock and the other three. It may be explained by assuming that the former was stopped by the earliest tremors, while the others continued their beats until the more forcible shocks at length stopped them.

In addition to the foregoing, the great clock in St. Michael's Church stopped a very little after $9^h\ 51^m$. As "town clocks" do not have any second hands, and as the error of this clock could not be ascertained, the value of this record for our purposes is very small. Three clocks in the office of the Western Union Telegraph Company were also reported stopped at $9^h\ 51^m$. They have no second hands, however, and their records are of no further value than to confirm in some measure the general tenor of the evidence that the nearest minute was $9^h\ 51^m$. They are of no utility in fixing the seconds.

Let us endeavor now to put these records of the four clocks into relation with what has already been inferred from wholly independent considerations concerning the duration of the earthquake and its component phases. We have already found reason for believing that the whole interval, from the earliest to the last percep-

tible tremors, was probably from sixty-five to seventy-five seconds; that the beginning consisted of light tremors, which increased in power through an interval of ten or fifteen seconds; that they suddenly swelled into the destructive phases of two maxima with an intervening minimum, of which the whole duration was from forty-five to fifty-five seconds; and that the concluding phase was a diminishing series of tremors lasting for eight or ten seconds. The clock of the South Carolina Railway, which stopped at $9^h$ $51^m$ $48^s$, is presumed to represent within a very few seconds of the beginning of the second maximum. Its error before the earthquake began could hardly have been more than a second or two, but it may have acquired several seconds of error during the first maximum and minimum, in which case the time of the second maximum would be correspondingly later. As it is quite impossible to assign a value to any such suddenly acquired error, there is apparently no alternative but to take the record at its face value. The other two railroad clocks, which stopped at $9^h$ $51^m$ $15^s$, are presumed to represent the time of the first maximum; not the exact beginning, but probably a very few seconds later. The manner in which they were arrested (by the catching of the points of the pendulums behind the arcs) seems to indicate that the shocks which stopped them must have had considerable amplitude transversely to the planes of oscillation, and must have acted upon the clocks at the precise moments when the pendulums were near the extremities of their arcs of vibration. The chances are that the pendulums were not caught in that particular way during the first three or four oscillations, but went staggering along for a few beats until finally caught. The errors of these clocks, however, may have been two or three seconds greater than that of the South Carolina Railway clock, as they had been running two days longer without correction. Furthermore, an interval of three or four seconds was probably occupied in the sudden swelling of the tremors from the preliminary milder phase into the full power of the first maximum. If we assume for the beginning of the first maximum an instant of time about three or four seconds earlier than that indicated by the two railroad clocks, i. e., $9^h$ $51^m$ $12^s$, our actual error will, I believe, not exceed five seconds. Finally, the clock of James Allan & Co. probably stopped at a slightly earlier phase. Mr. Allan states that the reading of the clock was $9^h$ $51^m$ exactly, but as regards its error he could only say that it did not exceed nine seconds, having compared his clock that day with the standard time signal, which he receives through a sounder telegraphically connected with the Western Union time-circuit; and his memory did not serve him as to how long it had been running without correction. If his clock may be assumed to have been six or eight seconds slow, making the true time of its arrest six or eight seconds after $9^h$ $51^m$, or four to six seconds earlier than the first maximum,

its stopping would have been easily possible; for many less sensitive clocks throughout the country were stopped by tremors no more forcible than those in Charleston at that particular phase.

It is plainly necessary to select some phase of the earthquake in Charleston as the beginning, with which the beginnings in all other places are to be compared. It must also be a phase at which the shocks had great power—sufficient indeed to make themselves felt hundreds of miles away. This phase is clearly that which has been called the beginning of the first maximum, and whose time has been estimated to be $9^h\ 51^m\ 12^s$. The probable error of this determination I judge to be very small. It still remains, however, to find from this the time to be correspondingly assigned to the beginning at the centrum. As the speed of propagation is now known to be somewhat in excess of three miles per second, and the computed distance from Charleston to the theoretic centrum is very nearly twenty miles, the time for the centrum is taken six seconds earlier than Charleston, or $9^h\ 51^m\ 6^s$, with the same probable error.

This conclusion receives general support from many considerations. There is no doubt or question that $9^h\ 51^m$ was the nearest minute to the time of beginning. The weight of testimony favoring a somewhat later instant is very strong and that favoring an earlier one is very weak. The time adopted consists far better with such positive evidence as stopped clocks can furnish than an earlier or later moment. Finally, it agrees better than any other with the great mass of time observations coming from other localities, as will appear in the course of subsequent discussion.

Having reached a conclusion as to the time at the origin, we may now proceed to examine the general list of time observations from all other localities.

The following is a general catalogue of all time reports received, excepting such as were so widely aberrant or so unintelligible as to render them wholly unworthy of even a moment's consideration. No report giving a time between the extremes of the list has been knowingly excluded from it, except a considerable number which state the time as being "about" or "near 10 o'clock." These are obviously too indefinite to be considered.

*List of time reports.*

| Locality. | Latitude. | Longitude. | Distance (statute miles). | Time ($9^h$ +). | Reporter. |
|---|---|---|---|---|---|
| | ° ′ | ° ′ | | *m. s.* | |
| Absecom, N. J | 39 26 | 74 30 | 553 | 52 00 | Light-keeper. |
| Adairsville, Ga | 34 23 | 84 52 | 295 | 55 00 | H. D. Capers. |
| Albany, N. Y. (*a*) | 42 40 | 73 45 | 770 | 55 00 | W. G. Tucker. |
| Do (*b*) | 42 40 | 73 45 | 770 | 56 40 | J. M. Clark. |
| Do | 42 40 | 73 45 | 770 | 61 00 | Associated Press. |
| Arlington, Tenn | 36 04 | 86 54 | 444 | 50 00 | W. C. Morris. |
| Asheville, N. C | 35 36 | 82 25 | 231 | 50 00 | Western Union Telegraph. |
| Ashland, Va | 37 45 | 77 27 | 367 | 52 00 | Richmond State. |
| Atlanta, Ga | 33 45 | 84 23 | 253 | 50 00 | W. E. Smith, Signal Service observer. |
| Do (*c*) | 33 45 | 84 23 | 253 | 52 00 | J. C. Hellman. |
| Do (*c*) | 33 45 | 84 23 | 253 | 52 00 | Do. |
| Do (*c*) | 33 45 | 84 23 | 253 | 52 30 | Do. |
| Do (*c*) | 33 45 | 84 23 | 253 | 53 00 | Do. |
| Do | 33 45 | 84 23 | 253 | 55 00 | Atlanta Constitution. |
| Atlantic City, N. J | 39 23 | 74 26 | 552 | 52 00 | |
| Do (*c*) | 39 23 | 74 26 | 552 | 54 00 | H. W. Hartley. |
| Do | 39 23 | 74 26 | 552 | 55 00 | A. J. Mitchell, Signal Service observer. |
| Auburn, Ala. (*d*) | 32 38 | 85 28 | 315 | 60 00 | P. H. Mell. |
| Augusta, Ga. (*e*) | 33 28 | 81 51 | 111 | 47 30 | Maj. J. W. Reilly, U. S. Army. |
| Do (*f*) | 33 28 | 81 51 | 111 | 51 00 | D. Fisher, Signal Service observer. |
| Do (*g*) | 33 28 | 81 51 | 111 | 52 00 | Do. |
| Do | 33 28 | 81 51 | 111 | 52 00 | A. G. Schultz. |
| Do (*c*) | 33 28 | 81 51 | 111 | 52 00 | Earle Sloan. |
| Do | 33 28 | 81 51 | 111 | 55 00 | C. de St. Roseana. |
| Do (*c*) | 33 28 | 81 51 | 111 | 55 18 | Earle Sloan. |
| Baldwin, Fla | 30 19 | 81 58 | 222 | 50 00 | Times-Union, Jacksonville, Fla. paper. |
| Baltimore, Md | 39 20 | 76 37 | 487 | 52 00 | P. B. Reese. |
| Do | 39 20 | 76 37 | 487 | 53 00 | New York Tribune "special." |
| Do | 39 20 | 76 37 | 487 | 53 20 | Richard Randolph. |
| Do | 39 20 | 76 37 | 487 | 55 00 | F. O'Beirne. |
| Beaver, Ohio (*h*) | 39 00 | 82 51 | 444 | 19 13 | J. M. Grether. |
| Bellows Falls, Vt. | 43 08 | 72 28 | 832 | 53 00 | H. Wells. (*i*) |
| Belvidere, N. Y. (*j*) | 40 50 | 75 09 | 622 | 54 00 | G. W. Holstein. |
| Blue Mountain Lake, N. Y. | 43 49 | 74 20 | 830 | 56 00 | Dr. E. Holden. |
| Boston, Mass | 42 22 | 71 05 | 832 | 53 00 | M. Irving. |
| Do | 42 22 | 71 05 | 832 | 58 00 | W. A. McLeod. |
| Branchville, S. C. (*k*) | ...... | ...... | 45 | 56 00 | Earle Sloan. |
| Brattleborough, Vt | 42 52 | 72 34 | 812 | 60 00 | No name (*l*). |
| Bristol, Tenn | 36 36 | 82 11 | 280 | 50 00 | J. R. Boyle, Western Union Telegraph operator. |
| Brooklyn, N. Y | 40 41 | 73 56 | 643 | 54 00 | C. H. Moseley (*m*). |
| Do | 40 41 | 73 56 | 643 | 54 00 | F. E. H. Haines (*n*). |
| Do | 40 41 | 73 56 | 643 | 55 00 | W. D. Halsey. |
| Do | 40 41 | 73 56 | 643 | 55 00 | Dr. S. S. Guy. |

*a* By watch compared with time of Dudley Observatory.
*b* New York State Museum of Natural History.
*c* Stopped clock.
*d* Alabama State Weather Bureau.
*e* Several clocks stopped at Augusta Arsenal.
*f* Given as first shock.
*g* Second shock.
*h* Columbus local time = 9.51.12 standard.
*i* Received through Prof. W. M. Davis.
*j* Began at 9.54, ended 9.59, by watch compared with railroad time.
*k* Stopped clock, probably second shock.
*l* Report forwarded by Prof. W. M. Davis.
*m* This report was signed by three others.
*n* States that the motion was over at 9.55.

*List of time reports*—Continued.

| Locality. | Latitude. | Longitude. | Distance (statute miles). | Time ($9^h$ +). | Reporter. |
|---|---|---|---|---|---|
| | ° ′ | ° ′ | | m. s. | |
| Brooklyn, N. Y. (*a*) | 40 41 | 73 56 | 643 | 55 00 | George Rankins. |
| Brookville, Ind | 39 26 | 84 59 | 526 | 53 00 | Amos Butler. |
| Brownsville, Tenn | 35 36 | 89 16 | 553 | 55 00 | W. A. Roberts. (*b*) |
| Brunswick, Ga | 31 12 | 81 27 | 155 | 52 00 | Morning News, of Savannah. |
| Buckhannon, W. Va | 38 57 | 80 16 | 419 | 56 00 | R. D. Lang. |
| Burlington, N. J | 40 04 | 74 51 | 584 | 50 00 | G. A. Appleton. |
| Do | 40 04 | 74 51 | 584 | 53 00 | Dr. N. Roe Bradner (*c*). |
| Cape Canaveral, Fla. (*d*) | | | | 58 00 | |
| Cairo, Ill | 37 00 | 89 11 | 588 | 53 00 | C. L. Bozzell, Signal Service observer. |
| Do (*e*) | 37 00 | 89 11 | 588 | 53 00 | Daily Telegram. |
| Camden, Ala. (*f*) | 31 59 | 87 12 | 425 | 58 48 | Postmaster. |
| Catlettsburgh, Ky. (*g*) | 38 24 | 82 37 | 405 | 20 00 | Louisville Commercial. |
| Do | 38 24 | 82 37 | 405 | 53 00 | L. D. Conghlan. |
| Do (*h*) | 38 24 | 82 37 | 405 | 53 00 | Western Union Telegraph. |
| Carrollton, Ala | 33 15 | 88 03 | 462 | 50 00 | M. L. Stansel. |
| Do | 33 15 | 88 03 | 462 | 60 00 | D. C. Hodo. |
| Carrollton, Ga | 33 36 | 85 04 | 290 | 50 00 | Morning News, Savannah paper. |
| Centre, Ala | 34 09 | 85 42 | 331 | 50 00 | Thomas Bradford. |
| Cedar Keys, Fla | 29 09 | 83 04 | 323 | 56 00 | W. W. Thomas, Signal Service observer. |
| Charleston, S. C. (*i*) | 32 50 | 79 55 | | 51 12 | C. E. Dutton. |
| Charleston, W. Va | 39 18 | 77 49 | 385 | 55 00 | Associated Press. |
| Chatham, Va | 36 50 | 79 25 | 272 | 51 00 | C. A. Douglass, telegraph operator. |
| Chattanooga, Tenn | 35 04 | 85 16 | 329 | 50 00 | Times, Chattanooga paper. |
| Do | 35 04 | 85 16 | 329 | 50 00 | H. M. Wettsee. |
| Do | 35 04 | 85 16 | 329 | 53 00 | E. A. Beals, Signal Service observer. |
| Do | 35 04 | 85 16 | 329 | 55 00 | New York Times. |
| Charlotte, N. C | 35 13 | 80 51 | 165 | 50 00 | Western Union Telegraph. |
| Do | 35 13 | 80 51 | 165 | 54 00 | J. A. Barry, Signal Service observer. |
| Chauncey, Ga | 32 05 | 83 00 | 182 | 55 00 | Morning News, Savannah paper. |
| Cheraw, S. C | 34 41 | 79 54 | 122 | 50 00 | W. L. Godfrey, Signal Service observer. |
| Chicago, Ill | 41 52 | 87 37 | 748 | 60 00 | Associated Press (*j*). |
| Do | 41 52 | 87 37 | 748 | 61 00 | A. Buell, Signal Service observer. |
| Cincinnati, Ohio (*k*) | 39 09 | 84 25 | 491 | 15 00 | Associated Press. |
| Do | 39 09 | 84 25 | 491 | 16 00 | Do. |
| Do (*l*) | 39 09 | 84 25 | 491 | 16 00 | Times-Star. |
| Do (*m*) | 39 09 | 84 25 | 491 | 16 00 | Do. |
| Do | 39 09 | 84 25 | 491 | 16 00 | Enquirer. |
| Do | 39 09 | 84 25 | 491 | 16 00 | C. Hellmuth. |
| Do | 39 09 | 84 25 | 491 | 16 00 | A. D. Rollins. |
| Do (*n*) | 39 09 | 84 25 | 491 | 16 40 | |

*a* Clock running accurately to standard time stopped.
*b* Through the Signal Service.
*c* States this time will not differ many seconds from standard time.
*d* Light-house clock stopped, its reading compared with railroad time.
*e* Clock in City National Bank stopped.
*f* Stopped clock given as 9.10 local time.
*g* Columbus local time = 9.52 standard.
*h* Clock stopped.
*i* Accepted time. For discussion (see page 358 et seq.
*j* Giving as authority the Signal Service observer.
*k* Cincinnati local time. The correction to the 75th meridian is $37^m\ 41^s$, making $9^h\ 52^m\ 41^s$.
*l* Time noted by clock in the office.
*m* Time given by the outside reporters.
*n* Large clock in fire-tower stopped at $9^h\ 16^m\ 17^s$. Its error was known exactly, viz: 23 seconds slow, making $9^h\ 16^m\ 40^s$ local = $9^h\ 54^m\ 21^s$ standard. Fully reported in Cincinnati papers.

*List of time reports*—Continued.

| Locality. | Latitude. | Longitude. | Distance (statute miles). | Time ($9^h$ +). | Reporter. |
|---|---|---|---|---|---|
| | ° ′ | ° ′ | | *m. s.* | |
| Cincinnati, Ohio (*a*) | 39 09 | 84 25 | 491 | 17 45 | Commercial Gazette. |
| Do (*b*) | 39 09 | 84 25 | 491 | 54 00 | Associated Press. |
| Clanton, Ala | 32 53 | 86 38 | 380 | 55 00 | S. A. Blaisingame. |
| Cleveland, Ohio | 41 30 | 81 42 | 604 | 54 00 | William Line, Signal Service observer. |
| Do | 41 30 | 81 42 | 604 | 54 00 | G. H. Tower, light-house keeper. |
| Climax, Ga | 30 54 | 84 28 | 295 | 50 00 | Morning News, of Savannah. |
| Collinwood, Ohio | ....... | ....... | ....... | 51 00 | P. L. Cobb. |
| Cochran, Ga. (*c*) | 32 21 | 83 19 | 192 | 52 00 | Q. L. Harvard. |
| Columbia, S. C. (*d*) | 34 00 | 81 06 | 89 | 51 00 | R. W. Shand. |
| Do | 34 00 | 81 06 | 89 | 52 00 | Earle Sloan. |
| Do (*d*) | 34 00 | 81 06 | 89 | 51 00 | Do. |
| Columbus, Ga | 32 27 | 84 54 | 287 | 48 00 | Augusta Chronicle. |
| Do | 32 27 | 84 54 | 287 | 50 00 | United Press. |
| Do | 32 27 | 84 54 | 287 | 56 00 | Enquirer-Sun. |
| Columbus, Miss. (*d*) | 33 27 | 88 23 | 481 | 56 00 | Dayton Hale. |
| Columbus, Ohio (*e*) | 39 58 | 83 00 | 513 | $21^1$ 00 | H. R. Giel, station master of Union Depot. |
| Do | 39 58 | 83 00 | 513 | 52 00 | A. L. McRae, Signal Service observer. |
| Do | 39 58 | 83 00 | 513 | $22^1$ 00 | Associated Press. |
| Do | 39 58 | 83 00 | 513 | 54 00 | Central Insane Asylum. |
| Do | 39 58 | 83 00 | 513 | 54 00 | Institute for the Blind. |
| Corinth, Miss | 34 55 | 88 27 | 500 | 55 00 | T. E. Henry. |
| Covington, Ky. (*f*) | 39 04 | 84 31 | 488 | $16^1$ 00 | J. Brookshaw. |
| Do (*g*) | 39 04 | 84 31 | 488 | 17 20 | I. J. Evans. |
| Covington, Tenn | 35 36 | 89 36 | 570 | 55 00 | D. T. Flannery, Signal Service observer. |
| Connersville, Ind | 39 33 | 85 05 | 543 | 52 00 | Robert Hessler. |
| Crawfordsville, Ind | 40 03 | 86 53 | 621 | 54 00 | E. C. Simpson. |
| Dale Enterprise, Va | 38 30 | 78 42 | 400 | 55 00 | L. J. Heathwole. |
| Darien, Ga. (*h*) | ....... | ....... | ....... | $28^1$ 00 | Times-Union. |
| Davenport, Iowa | 41 30 | 90 33 | 827 | 55 00 | A. S. Tiffany. |
| Dayton, Ky. (*i*) | 39 04 | 84 29 | 488 | 16 30 | F. J. Sutton. |
| Dayton, Tenn | 35 28 | 84 51 | 330 | 50 00 | W. H. C. Brown. |
| Daytona, Fla. (*j*) | 29 10 | 81 05 | 277 | $25^1$ 00 | Halifax Journal, of Daytona. |
| Decatur, Ala. | 34 36 | 86 55 | 412 | 53 00 | A. C. Frey, Signal Service observer. |
| De Land, Fla | 29 03 | 81 20 | 291 | 50 00 | Times-Union, of Jacksonville. |
| Delaware Breakwater, Del. | 38 49 | 75 07 | 500 | 55 00 | Associated Press. |
| Detroit, Mich | 42 20 | 83 03 | 675 | 55 00 | J. T. Whiting. |
| Do | 42 20 | 83 03 | 675 | 55 00 | Free Press, of Detroit. |
| Do | 42 20 | 83 03 | 675 | 55 00 | Abend-Post, of Detroit. |
| Do | 42 20 | 83 03 | 675 | 55 00 | L. H. Trowbridge. |

*a* Noted in newspaper office after first shock $=9^h\ 55^m\ 26^s$ standard.

*b* The Cincinnati and many other papers state that several clocks in the office of the Western Union Telegraph Company stopped at $9^h\ 54^m$. The telegraph company at Cincinnati furnish standard time, while the telephone company and Duhme & Co. furnish very accurate local time obtained from the Cincinnati Observatory.

*c* Two clocks, "well regulated," stopped.

*d* Stopped clock.

*e* Columbus local time; correction to $75^{th}$ meridian—$32^m$ exactly—making $9^h\ 53^m$ standard.

*f* Cincinnati local$=9^h\ 53^m\ 41^s$ standard.

*g* Jeweler's regulator stopped$=9^h\ 55^m\ 1^s$ standard.

*h* Savannah local$=9^h\ 53^m$ standard.

*i* Cincinnati local$=9^h\ 54^m\ 11^s$ standard.

*j* If this is Savannah local, it is $9^h\ 50^m$ standard; it is a doubtful observation.

*List of time reports*—Continued.

| Locality. | Latitude. | Longitude. | Distance (statute miles). | Time ($9^h$ +). | Reporter. |
|---|---|---|---|---|---|
| | ° ′ | ° ′ | | *m. s.* | |
| Detroit, Mich | 42 20 | 83 03 | 675 | 56 00 | J. M. Power. |
| Do | 42 20 | 83 03 | 675 | 58 00 | H. M. Baldwin, Signal Service observer. |
| Dighton, Mass | 41 49 | 71 08 | 812 | 56 00 | E. Jaeger. |
| Dyersburg, Tenn | 36 03 | 89 24 | 569 | 54 00 | Louis Hughes. |
| Dubuque, Iowa (*a*) | 42 29 | 90 40 | 878 | 57 00 | Dr. Asa Horr. |
| Do | 42 29 | 90 40 | 878 | 58 00 | Dubuque Herald. |
| Do | 42 29 | 90 40 | 878 | 62 00 | S. E. Emery. |
| East Saginaw, Mich | 43 27 | 83 57 | 766 | 58 00 | Free Press, of Detroit. |
| Ellaville, Fla | 30 24 | 83 13 | 259 | 55 00 | Times-Union, of Jacksonville. |
| Evansville, Ind | 38 01 | 87 33 | 545 | 54 00 | F. W. Norton. |
| Fernandina, Fla. (*b*) | 30 41 | 81 26 | 225 | 28[1] 00 | Morning News, of Savannah. |
| Fonda, N. Y | 42 58 | 74 20 | 775 | 55 00 | F. L. Yates. |
| Fortress Monroe, Va | 37 00 | 76 16 | 356 | 55 00 | J. B. Jones. |
| Frankfort, Ind | 40 18 | 86 31 | 621 | 55 00 | W. S. Sims. |
| Gowanda, N. Y | 42 28 | 78 57 | 666 | 55 00 | W. R. Smallwood. |
| Grand Haven, Mich | ...... | ....... | ....... | 48 00 | J. E. Muller. |
| Grand Junction, Tenn | 35 04 | 89 10 | 538 | 55 00 | J. B. Irwin. |
| Greenfield, Mass | 42 36 | 72 36 | 799 | 55 00 | G. R. Knapp. |
| Greensborough, Ala | 32 43 | 87 36 | 435 | 60 00 | Daily Dispatch, of Montgomery, Ala. |
| Hackensack, N. J | 40 53 | 74 03 | 654 | 54 00 | J. H. Andrews. |
| Hamilton, Ohio (*c*) | 39 27 | 84 33 | 513 | 16 30 | W. Schlosser. |
| Hartford, Conn | 41 31 | 72 21 | 747 | 54 00 | A. H. Eddy. |
| Do | 41 31 | 72 21 | 747 | 55 30 | E. M. White. |
| Hatteras, N. C | 35 11 | 75 43 | 309 | 60 00 | A. S. White. |
| Havre de Grace, Md. (*d*) | 39 33 | 76 07 | 515 | 55 00 | W. P. Sauerhoff, U. S. Fish Commission. |
| Helena, Ark | 34 33 | 90 32 | 609 | 55 00 | J. B. Mills. |
| Hudson, N. Y | 42 14 | 73 44 | 747 | 57 00 | Associated Press. |
| Indianapolis, Ind | 39 46 | 86 10 | 581 | 52 00 | Do. |
| Do | 39 46 | 86 10 | 581 | 55 00 | Do. |
| Do | 39 46 | 86 10 | 581 | 55 00 | Journal, of Indianapolis. |
| Do | 39 46 | 86 10 | 581 | 55 00 | C. F. R. Wappenhaus, Signal Service observer. |
| Do (*e*) | 39 46 | 86 10 | 581 | 55 00 | Journal. |
| Iowa City, Iowa | 41 39 | 91 32 | 870 | ........ | Prof. F. E. Nipher (*f*). |
| Ironton, Ohio (*g*) | 38 37 | 82 42 | 414 | 23[1] 00 | Times-Star, of Cincinnati. |
| Ithaca, N. Y. (*h*) | 42 24 | 76 36 | 696 | 55 00 | New York Tribune. |
| Jacksonville, Fla. (*i*) | 30 20 | 81 39 | 211 | 27[1] 00 | Associated Press. |
| Do (*j*) | 30 20 | 81 39 | 211 | 52 00 | United Press. |
| Do | 30 20 | 81 39 | 211 | 52 00 | Times-Union, of Jacksonville. |
| Do | 30 20 | 81 39 | 211 | 52 00 | J. W. Smith, Signal Service observer. |
| Do | 30 20 | 81 39 | 211 | 56 00 | J. Hensien. |
| Jamaica Plain, Mass | 42 19 | 71 07 | 823 | 57 00 | E. H. Richards. |
| Jamestown, N. Y | 42 06 | 79 14 | 642 | 56 00 | New York World. |

*a* Estimated by repeating and timing certain movements.
*b* Equals $9^h$ $53^m$ standard.
*c* Cincinnati local = $9^h$ $54^m$ $11^s$ standard.
*d* Clock regulated carefully to railroad time stopped.
*e* Great clock in tower of city court-house stopped.
*f* Reports a few minutes, not exceeding 5, before 9 p. m. central time.
*g* This is Columbus local time = $9^h$ $55^m$ standard.
*h* Clock in railroad station "stopped at $9^h$ $55^m$ exactly."
*i* Savannah local time = $9^h$ $52^m$ standard.
*j* Stopped clock.

*List of time reports*—Continued.

| Locality. | Latitude. | Longitude. | Distance (statute miles). | Time ($9^h$ +). | Reporter. |
|---|---|---|---|---|---|
| | ° ′ | ° ′ | | *m. s.* | |
| Jasper, Ind | 38 26 | 86 57 | 540 | 55 00 | A. M. Sweeney. |
| Keokuk, Iowa | 40 23 | 91 26 | 810 | 56 00 | S. R. Palfrey. |
| Do | 40 23 | 91 26 | 810 | 56 00 | Garden City Weekly. |
| Kitty Hawk, N. C | 36 06 | 75 48 | 335 | 60 00 | P. W. Fitzmaurice. |
| Knoxville, Tenn | 35 56 | 83 58 | 302 | 54 00 | New York Times special. |
| Do | 35 56 | 83 58 | 302 | 55 00 | W. O. Bailey, Signal Service observer. |
| Lake Annie, Fla | 27 12 | 81 19 | 416 | 50 00 | Times-Union. |
| Lake Placid, N. Y | 44 18 | 73 55 | 827 | 55 00 | Prof. B. W. Frazer. |
| Lancaster, Ohio (*a*) | 39 46 | 82 40 | 491 | $22^1$ 00 | Commercial Gazette, of Cincinnati; also the Enquirer special. |
| Lancaster, S. C. (*b*) | 34 42 | 80 47 | 126 | 55 00 | J. H. Foster. |
| Langley, S. C. (*b*) | ........ | ........ | 102 | 53 00 | Earle Sloan. |
| Laurinburgh, N. C | 34 48 | 79 25 | 135 | 51 00 | A. Tischbein. |
| Lexington, Ky. (*c*) | 38 02 | 84 33 | 432 | $15^1$ 00 | Associated Press. |
| Lincolnton, N. C | 35 29 | 81 12 | 187 | 55 00 | E. R. Standemeyer. |
| Lockland, Ohio (*d*) | 39 16 | 84 30 | 505 | $15^1$ 00 | Lockland newspaper. |
| Do (*d*) | 39 16 | 84 30 | 505 | $16^1$ 00 | Do. |
| Do (*d*) | 39 16 | 84 30 | 505 | $17^1$ 00 | Do. |
| Do (*d*) | 39 16 | 84 30 | 505 | $19^1$ 00 | Do. |
| London, Ont | 42 59 | 81 15 | 706 | 55 00 | New York Tribune. |
| Louisville, Ky. (*e*) | 38 15 | 85 45 | 485 | $11^1$ 00 | Commercial, of Louisville. |
| Do | 38 15 | 85 45 | 485 | 55 00 | Post, of Louisville. |
| Do | 38 15 | 85 45 | 485 | 55 17 | Prof. R. B. Thurston, of Kentucky State Geological Survey. |
| Lynchburgh, Va | 37 25 | 79 09 | 316 | 50 00 | Dispatch, of Richmond, Va. |
| Do | 37 25 | 79 09 | 316 | 55 00 | T. S. Schley. |
| Macon, Ga. (*f*) | 32 49 | 83 33 | 203 | 51 30 | R. T. Hoge. |
| Do (*g*) | 32 49 | 83 33 | 203 | 52 00 | Do. |
| Madison, Ind. (*h*) | 38 46 | 85 24 | 500 | $15^1$ 00 | J. H. Woolford. |
| Mannington, Ky. (*h*) | 39 04 | 84 30 | 488 | $15^1$ 00 | J. H. Allen. |
| Manistee, Mich. (*b*) | 44 18 | 86 17 | 855 | 57 00 | J. H. Roberts. |
| Meadville, Pa. (*b*) | 41 39 | 80 12 | 608 | 55 00 | W. E. Cruickshanks. |
| Media, Pa | 39 55 | 75 24 | 557 | 60 00 | Times, of Philadelphia. |
| Memphis, Tenn. (*i*) | 35 09 | 90 03 | 587 | 54 00 | D. T. Flannery. |
| Do | 35 09 | 90 03 | 587 | 55 00 | Do (*j*). |
| Do (*k*) | 35 09 | 90 03 | 587 | 55 00 | Do. |
| Do (*l*) | 35 09 | 90 03 | 587 | 55 00 | Do. |
| Do | 35 09 | 90 03 | 587 | 55 00 | Do. |
| Do | 35 09 | 90 03 | 587 | 55 00 | Do. |
| Do (*m*) | 35 09 | 90 03 | 587 | 57 00 | Do. |
| Do (*n*) | 35 09 | 90 03 | 587 | 59 00 | Do. |

*a* Columbus local = $9^h$ $54^m$ standard.
*b* Clock stopped.
*c* Cincinnati local = $9^h$ $52^m$ $41^s$ standard.
*d* These are all stopped clocks; the time is Cincinnati local; correction to 75th meridian + $37^m$ $41^s$.
*e* Correction to 75th meridian + $43^m$.
*f* Large clock in Union Railroad station stopped either at $9^h$ $51^m$ $20^s$ or $9^h$ $51^m$ $40^s$; is uncertain which.
*g* Observation by watch regulated by the above clock.
*h* Cincinnati local = $9^h$ $52^m$ $41^s$ standard.
*i* Clock in city surveyor's office stopped.
*j* Signal Service observer; clock in his own office stopped.
*k* Baltimore and Ohio Telegraph office clock stopped.
*l* This and the two following clocks stopped; reported to Sergt. D. T. Flannery by Byrd & Co., who provide accurate time for the city.
*m* Clock of Babb & Co. stopped.
*n* Clock in United States Marine Hospital stopped.

*List of time reports*—Continued.

| Locality. | Latitude. | Longitude. | Distance (statute miles). | Time ($9^h$ +). | Reporter. |
|---|---|---|---|---|---|
| | ° ′ | ° ′ | | *m. s.* | |
| Meridian, Miss. (*a*) | 32 20 | 88 40 | 500 | 54 00 | G. Helmick. |
| Milan, Tenn | 35 56 | 88 58 | 530 | 57 00 | O. F. Cantwell. |
| Mobile, Ala | 30 41 | 88 02 | 493 | 50 00 | United Press. |
| Montgomery, Ala | 32 23 | 86 18 | 363 | 55 00 | Dispatch, of Montgomery, Ala. |
| Morristown, N. J. | 40 48 | 74 27 | 637 | 55 00 | T. J. Beans. |
| Mount Vernon, Ohio (*b*) | 40 27 | 82 33 | 536 | 24' 00 | Enquirer, of Cincinnati. |
| Nashville, Tenn. (*c*) | 36 09 | 86 52 | 438 | 53 30 | J. D. Leonard. |
| Do (*d*) | 36 09 | 86 52 | 438 | 54 12 | Do. |
| Do | 36 09 | 86 52 | 438 | 54 30 | L. W. Jesunofsky. |
| Newark, N. J | 40 44 | 74 20 | 640 | 53 00 | W. Hanlon. |
| Do (*e*) | 40 44 | 74 20 | 640 | 55 00 | E. R. Ball. |
| New Castle, Del. (*d*) | 39 39 | 75 35 | 538 | 54 00 | A. S. Denny. |
| New Castle, Pa. (*d*) | 41 01 | 80 24 | 565 | 55 00 | J. M. Butz. |
| New Castle, Ind | 39 58 | 85 23 | 566 | 55 00 | W. M. Pence. |
| New Haven, Conn | 41 19 | 72 25 | 711 | 55 30 | J. H. Sherman, Signal Service observer. |
| Do | 41 19 | 72 25 | 711 | 55 30 | Associated Press. |
| New Philadelphia, Ohio | 40 31 | 81 29 | 532 | 54 00 | Enquirer, of Cincinnati. |
| Newport, Ky. (*f*) | 39 04 | 84 30 | 488 | 15 40 | J. Brookshaw. |
| New York, N. Y | 40 45 | 73 58 | 645 | 53 00 | A. J. Campbell. |
| Do | 40 45 | 73 58 | 645 | 53 00 | W. F. Robinson, Signal Service observer. |
| Do | 40 45 | 73 58 | 645 | 53 00 | H. J. Penrod. |
| Do | 40 45 | 73 58 | 645 | 54 00 | Police headquarters. |
| Do | 40 45 | 73 58 | 645 | 54 00 | A. Parkman. |
| Do | 40 45 | 73 58 | 645 | 54 30 | M. C. Whitney. |
| Do | 40 45 | 73 58 | 645 | 54 30 | Western Union Telegraph operator (*g*). |
| Do | 40 45 | 73 58 | 645 | 55 00 | Carl Richter. |
| Do | 40 45 | 73 58 | 645 | 55 00 | S. H. Hurd. |
| Do | 40 45 | 73 58 | 645 | 55 00 | Light-house, Governor's Island, New York Harbor. |
| Do | 40 45 | 73 58 | 645 | 55 00 | New York Herald (*h*). |
| Do | 40 45 | 73 58 | 645 | 55 00 | F. C. Roe. |
| Do (*i*) | 40 45 | 73 58 | 645 | 55 00 | W. D. Halsey. |
| Do (*j*) | 40 45 | 73 58 | 645 | 55 30 | New York Tribune. |
| Do | 40 45 | 73 58 | 645 | ...... | |
| Norfolk, Va | 36 51 | 76 17 | 349 | 54 00 | J. P. Sherry, Signal Service observer. |
| North Manchester, Ind | 41 00 | 85 46 | 640 | 50 00 | A. Miller. |
| Oakland, Ill | ...... | ...... | ...... | 50 00 | W. J. Peak. |
| Oakland, Md | 39 25 | 79 25 | 455 | 55 00 | P. Hamill. |
| Olustee, Fla. (*k*) | 30 11 | 82 30 | 255 | 28' 00 | Times-Union. |
| Orange, N. J | 40 46 | 74 14 | 642 | 55 00 | P. E. Bogert. |
| Orangeburgh, S. C | 33 31 | 80 51 | 58 | 48 00 | R. Means Davis. |
| Opelika, Ala | 32 38 | 85 23 | 307 | 55 00 | G. E. Webber. |
| Oswichee, Ala | 32 10 | 85 00 | ...... | 60 00 | W C. Whitaker. |

*a* Clock "kept by standard time" stopped.
*b* The time is Columbus local=$9^h$ $56^m$ standard.
*c* Beginning of shocks.
*d* Clock stopped.
*e* Clock "carefully regulated to standard time" stopped.
*f* Cincinnati local=$9^h$ $53^m$ $21^s$ standard.
*g* "Had just sent a dispatch marked $9^h$ $54^m$."
*h* Noted in the office of that paper.
*i* Stopped clock Postal Telegraph Company.
*j* Stopped clock in large building 117 Duane street and 34 Thomas street.
*k* Savannah local=$9^h$ $53^m$ standard.

*List of time reports*—Continued.

| Locality. | Latitude. | Longitude. | Distance (statute miles). | Time ($9^h$ +). | Reporter. |
|---|---|---|---|---|---|
| | ° ′ | ° ′ | | *m. s.* | |
| Oxford, Miss | 34 22 | 89 32 | 548 | 56 00 | R. B. Fulton. |
| Oxford, Md | 38 40 | 76 12 | 460 | 50 00 | R. E. Nelson. |
| Paducah, Ky | 37 05 | 88 36 | 558 | 52 15 | J. R. Cobourn, Western Union Telegraph. |
| Palatka, Fla. (*a*) | ........ | ........ | ...... | $28^1$ 00 | Times-Union. |
| Paris, Tenn | 36 18 | 88 21 | 520 | 56 00 | E. P. Wood. |
| Parkersburgh, W. Va | 39 15 | 81 37 | 448 | 55 00 | W. H. Walker. |
| Pensacola, Fla | 30 25 | 87 13 | 457 | 60 00 | W. L. Wedemeyer, Signal Service observer. |
| Peoria, Ill | ........ | ........ | 710 | 55 00 | A. G. Palmer, engineer of Peoria and Decatur Railroad. |
| Philadelphia, Pa | 39 57 | 75 09 | 566 | 50 00 | L. W. Dey, Signal Service observer. |
| Do | 39 57 | 75 09 | 566 | 52 00 | United Press. |
| Do | 39 57 | 75 09 | 566 | 53 00 | Associated Press. |
| Pikesville, Md | 39 22 | 76 43 | 490 | 53 30 | C. R. Goodwin. |
| Plainfield, N. J | 40 14 | 74 25 | 625 | 55 00 | G. H. Frost. |
| Pittsburgh, Pa | 40 32 | 80 00 | 525 | 54 00 | Despatch, of Pittsburgh. |
| Do (*b*) | 40 32 | 80 00 | 525 | 55 00 | Despatch. |
| Do | 40 32 | 80 00 | 525 | 55 00 | O. D. Stewart, Signal Service observer. |
| Port Huron, Mich | 42 58 | 82 29 | 674 | 55 00 | W. M. Edmondson. |
| Portsmouth, Ohio (*c*) | 38 49 | 83 03 | 433 | $24^1$ 00 | Signal Service observer. |
| Prairie du Chien, Wis. (*d*) | 43 03 | 91 11 | 924 | 56 00 | J. G. Hagan, S. J. |
| Pungoteague, Va | 37 38 | 75 49 | 410 | 53 00 | T. H. Ireland. |
| Raleigh, N. C | 35 46 | 78 39 | 213 | 50 00 | C. L. McArthur. |
| Richmond, Va | 37 32 | 77 22 | 354 | 55 00 | J. B. Tree. |
| Rome, Ga. (*e*) | 34 15 | 85 03 | 302 | 59 00 | W. H. Adkins, Western Union Telegraph operator. |
| Rutherfordton, N. C | 35 24 | 81 50 | 200 | 50 00 | A. L. Grayson. |
| Sanford, Fla | 28 48 | 81 23 | 305 | 50 00 | H. Pennywitt, Signal Service observer. |
| Do | 28 48 | 81 23 | 305 | 56 00 | C. F. Sweeney. |
| Saratoga, N. Y | 43 04 | 73 45 | 797 | 53 00 | H. J. Horn. |
| Savannah, Ga | 32 05 | 81 08 | 89 | 51 40 | A. F. Flint. |
| Do (*f*) | 32 05 | 81 08 | 89 | 51 51 | Morning News. |
| Do | 32 05 | 81 08 | 89 | 52 00 | R. Graham, Signal Service observer. |
| Do | 32 05 | 81 08 | 89 | 52 00 | Morning News. |
| Selin's Grove, Pa | 40 48 | 76 53 | 585 | 55 00 | J. G. L. Shindell. |
| Selma, Ala | ........ | ........ | ........ | 60 00 | Daily Despatch, of Montgomery, Ala. |
| Sewickley, Pa. (*g*) | 40 34 | 80 13 | 535 | $34^1$ 00 | S. H. Murray. |
| Shelby Iron Works, Ala | 33 08 | 86 31 | 377 | 54 00 | A. A. Wright. |
| Smithville, N. C | 33 55 | 78 01 | 137 | 50 00 | F. P. Chaffee, Signal Service observer. |
| Do | 33 55 | 78 01 | 137 | 54 00 | E. S. Martin. |
| Somerset, Ky | 37 06 | 84 42 | 386 | 59 00 | S. Whinery. |
| Spencer, Ind | 39 18 | 86 47 | 577 | 55 00 | Journal, of Indianapolis. |
| Statesburgh, S. C | 33 59 | 80 33 | 80 | 51 30 | W. W. Anderson. |
| Stockbridge, Mass | 42 18 | 73 21 | 765 | 56 00 | J. O. Jacob. |
| Stuyvesant, N. Y | 42 22 | 73 43 | 760 | 57 00 | F. Peters. |

*a* $9^h$ $53^m$ standard.
*b* Clock stopped in Western Union Telegraph office.
*c* Columbus local time=$9^h$ $56^m$ standard.
*d* Estimated.
*e* Stopped clock.
*f* Large clock in Union Depot stopped.
*g* Pittsburgh local time=$9^h$ $54^m$ standard.

*List of time reports*—Continued.

| Locality | Latitude. | Longitude. | Distance (statute miles). | Time ($9^h$ +). | Reporter |
|---|---|---|---|---|---|
| | ° ′ | ° ′ | | *m. s.* | |
| Sullivan, Ill | ..... | ........ | ........ | 50 00 | B. F. Peadro. |
| Terre Haute, Ind | 39 29 | 87 25 | 606 | 55 00 | M. Straus. |
| Thomasville, Ga | 30 47 | 84 01 | 273 | 52 20 | Morning News, of Savannah. |
| Titusville, Pa | 41 38 | 79 42 | 608 | 56 00 | Associated Press. |
| Toledo, Ohio | 41 39 | 83 34 | 637 | 55 00 | G. E. Pomeroy. |
| Toronto, Ontario (*a*) | 43 39 | 79 22 | 753 | ........ | C. Carpmael. |
| Tracy City, Tenn | 35 17 | 85 50 | 360 | 50 00 | W. T. Thomas. |
| Tuscaloosa, Ala | 33 13 | 87 32 | 432 | 55 00 | United Press. |
| Union Springs, Ala | ........ | ........ | ........ | 60 00 | J. L. Moultrie. |
| Uniontown, Pa | 39 55 | 79 44 | 487 | 55 00 | F. C. Robinson. |
| University, Ala | ........ | ........ | ........ | 52 00 | P. H. Mell. |
| Valley Head, Ala | ........ | ........ | ........ | 60 00 | E. P. Nicholson. |
| Valparaiso, Ind | 41 28 | 87 03 | 705 | 53 00 | Frank Grenaw. |
| Warsaw, N. Y | 42 45 | 78 10 | 700 | 55 00 | H. K. Faunce. |
| Warwick, N. Y | 41 16 | 74 19 | 661 | 56 00 | G. W. Tinlaw. |
| Washington, D. C | 38 53 | 77 01 | 452 | 53 00 | Commander T. S. Looker, U. S. Navy. |
| Do | 38 53 | 77 01 | 452 | 53 20 | Prof. S. Newcomb. |
| Do | 38 53 | 77 01 | 452 | 53 23 | Alex. McAdie, United States Signal Service. |
| Do | 38 53 | 77 01 | 452 | 53 15 | W. C. Winlock, assistant, United States Naval Observatory. |
| Do | 38 53 | 77 01 | 452 | 54 00 | General M. C. Meigs, U. S. Army. |
| Do | 38 53 | 77 01 | 452 | 54 30 | W J McGee, U. S. Geological Survey. |
| Washingtonville, N. Y | 41 26 | 74 09 | 680 | 55 00 | New York Times. |
| Waycross, Ga | 31 13 | 82 13 | 183 | 55 00 | Morning News, of Savannah. |
| Weldon, N. C | 36 27 | 77 38 | 281 | 50 00 | F. A. Clark. |
| Wellsville, Ohio | 40 38 | 80 42 | 538 | 55 00 | G. W. Gillespie. |
| Woodbury, N. J | 39 39 | 75 10 | 557 | 57 00 | Edward Brown. |
| Woodstock, Md | 39 22 | 76 56 | 502 | 55 00 | Signal Service observer. |
| Wooster, Ohio (*b*) | 40 48 | 81 59 | 558 | 55 45 | W. Bennet. |
| Wyoming, Ohio (*c*) | ........ | ........ | ........ | 16l 00 | T. H. Diel. |
| Wytheville, Va (*d*) | 36 57 | 81 10 | 284 | 52 37 | Howard Shriver. |
| Zellwood, Fla. (*d*) | 28 45 | 81 38 | 306 | 28l 00 | Morning News. |
| Do | 28 45 | 81 38 | 306 | 55 00 | R. G. Robinson. |

*a* A magnetographic record.
*b* Stopped clock.
*c* Cincinnati local = $9^h$ $53^m$ $41^s$ standard.
*d* Savannah local = $9^h$ $53^m$ standard.

In the foregoing catalogue the latitudes and longitudes have been taken from Rand & McNally's Atlas. The distances are from the centrum, 16½ miles N. 30° W. of Charleston, and have been measured upon the Land Office map of the United States. The scale of the map is 40 statute miles to the inch. Individual errors in the distances may be as great as three miles. Some of thê times given are local. Wherever these occur pains have been taken to ascertain what cor-

rections are necessary to reduce them to the 75th meridian. They are as follows:

| | *m.* | *s.* |
|---|---|---|
| Pittsburgh | 20 | 00 |
| Columbus, O. | 32 | 00 |
| Cincinnati | 37 | 41 |
| Louisville, Ky. | 43 | 00 |
| Georgia and Florida | 25 | 00 |

With the exception of Cincinnati, the above localities use an integral number of minutes for the difference between local and standard time, and in Pittsburgh, Columbus, and Louisville the true corrections are almost exact minutes.

In order that it may be seen at a glance how these observations tend to group themselves, the following summary is given:

RECAPITULATION.

| | | |
|---|---|---|
| Reports giving | $9^h$ $47^m$ and seconds | 1 |
| | 9 48 | 3 |
| | 9 50 | 32 |
| | 9 51 | 6 |
| | 9 51 and seconds | 6 |
| | 9 52 | 25 |
| | 9 52 and seconds | 9 |
| | 9 53 | 28 |
| | 9 53 and seconds | 16 |
| | 9 54 | 31 |
| | 9 54 and seconds | 9 |
| | 9 55 | 86 |
| | 9 55 and seconds | 8 |
| | 9 56 | 21 |
| | 9 56 and seconds | 2 |
| | 9 57 | 8 |
| | 9 58 | 5 |
| | 9 58 and seconds | 1 |
| | 9 59 | 3 |
| | 10 00 | 13 |
| | 10 01 | 2 |
| | 10 02 | 1 |
| Total | | 316 |

In this list there are but four reports giving a time earlier than $9^h$ $50^m$, and only three giving a time later than $10^h$. The large number giving $9^h$ $50^m$, $9^h$ $55^m$, and $10^h$ is a striking feature, illustrating the tendency to specify time in minutes which are multiples of five. In expurgating this list it is obvious enough that all giving $9^h$ $50^m$ should be thrown out, because they give an earlier time than the time at Charleston. Those giving 10 o'clock form an isolated or discontinuous group and should also be thrown out. This will appear more clearly when we come to examine those which give $9^h$ $59^m$, every one of which must be rejected on its merits, as involving a large error. Thus the first $9^h$ $59^m$ is a stopped clock at Rome, Ga. As this clock

was carefully regulated, and was probably less than half a minute in error, we can only suppose that it was stopped by the second shock, which left the centrum about five or six minutes after the first and greatest shocks. The second $9^h$ $59^m$ is from the clock of the Marine Hospital at Memphis, Tenn. Sergeant Flannery, the Signal Office observer, has reported no less than eight clocks stopped at that place, one of which gives $9^h$ $54^m$, five give $9^h$ $55^m$, one $9^h$ $57^m$, and one $9^h$ $59^m$. We have no alternative but to discard the last two as involving large unexplained errors. The third $9^h$ $59^m$ comes from Somerset, in Kentucky. As the other localities in its neighborhood give $9^h$ $53^m$ to $9^h$ $55^m$, it involves so wide a discrepancy, that it must be rejected. The single observation of $9^h$ $58^m$ $48^s$, from Camden, Ala., is also a stopped clock, running upon local time, but of what locality is not known. It is an uncertain observation, and this uncertainty would alone cause its rejection, even if it had not been abnormal. Thus an interval of two minutes separates the 10 o'clock observations from all earlier times, and as they are abnormal as well as isolated, they must all be rejected. The three observations later than 10 o'clock all come from localities which give much better observations, which are earlier, except one from Chicago. This is an uncertain observation, and standing alone so far from all others, it must be rejected as being abnormal. Thus all accepted times must fall between $9^h$ $51^m$ and $9^h$ $58^m$.

It is a difficult matter to deal satisfactorily with those giving $9^h$ $55^m$. There are no less than 86 of them. The only course which has suggested itself is to reject all except those which give internal evidence that this was really the nearest observed minute, and not merely the nearest observed multiple of five minutes. This excludes half of them at once. Very probably this throws out some good observations. But it is better to do this than to admit them all, knowing that by so doing we should admit a systematic error whose effect we have no means of computing. The following list comprises the observations which have been rejected, and the column of remarks sets forth the reason why in each case:

*List of rejected observations.*

| Locality. | Distance. | Time. | Remarks. |
|---|---|---|---|
| | | *m. s.* | |
| Absecom, N. J. | 553 | 52 00 | Too early. |
| Adairsville, Ga. | 295 | 55 00 | Multiple of 5. |
| Albany, N. Y | 770 | 61 00 | Too late and two better reports. |
| Arlington, Tenn | 444 | 50 00 | |
| Asheville, N. C. | 231 | 50 00 | |
| Atlanta, Ga. | 253 | 50 00 | |
| Do | 253 | 55 00 | Multiple of 5. |
| Atlantic City, N. J. | 552 | 52 00 | Too early. |

*List of rejected observations*—Continued.

| Locality. | Distance. | Time. | Remarks. |
|---|---|---|---|
| | | *m. s.* | |
| Atlantic City, N. J | 552 | 55 00 | Multiple of 5. |
| Auburn, Ala | 315 | 60 00 | |
| Augusta, Ga | 111 | 47 30 | Too early. |
| Do | 111 | 52 00 | Stated to be second shock. |
| Do | 111 | 55 00 | Multiple of 5. |
| Do | 111 | 55 18 | Stopped clock; too late. |
| Baldwin, Fla | ....... | 50 00 | |
| Baltimore, Md | 487 | 52 00 | Too early. |
| Do | 487 | 55 00 | Multiple of 5. |
| Beaver, Ohio | 444 | 51 32 | Too early. |
| Branchville, S. C | 45 | 56 00 | Too late. |
| Brattleborough, Vt | 812 | 60 00 | |
| Bristol, Tenn | 280 | 50 00 | |
| Brownsville, Tenn | 553 | 55 00 | Multiple of 5. |
| Buckhannon, W. Va | 419 | 56 00 | Too late. |
| Burlington, N. J | 584 | 50 00 | |
| Cape Canaveral, Fla | ....... | 58 00 | Probably second shock. |
| Camden, Ala | 425 | 58 28 | Probably second shock; also uncertain local time. |
| Carrollton, Ala | 462 | 50 00 | |
| Do | 462 | 60 00 | |
| Carrollton, Ga | 290 | 50 00 | |
| Centre, Ala | 331 | 50 00 | |
| Cedar Keys, Fla | 323 | 56 00 | Too late. |
| Charleston, W. Va | 385 | 55 00 | Multiple of 5. |
| Chatham, Va | 272 | 51 00 | Too early. |
| Chattanooga, Tenn | 329 | 50 00 | |
| Do | 329 | 50 00 | |
| Do | 329 | 55 00 | Multiple of 5. |
| Charlotte, N. C | 165 | 50 00 | |
| Do | 165 | 54 00 | Too late. |
| Chauncey, Ga | 182 | 55 00 | Multiple of 5. |
| Cheraw, S. C | 122 | 50 00 | |
| Chicago, Ill | 784 | 60 00 | |
| Do | 784 | 61 00 | Too late. |
| Cincinnati, Ohio | 491 | 52 41 | Multiple of 5, given as 9.15 local; too early. |
| Do | 491 | 55 26 | Too late, and seven better observations. |
| Clanton, Ala | 380 | 55 00 | Multiple of 5. |
| Climax, Ga | 295 | 50 00 | |
| Collinwood, Ohio | ....... | 51 00 | Too early. |
| Columbus, Ga | 287 | 48 00 | Do. |
| Do | 287 | 50 00 | |
| Do | 287 | 56 00 | Too late. |
| Columbus, Ohio | 513 | 52 00 | Too early. |
| Corinth, Miss | 500 | 55 00 | Multiple of 5. |
| Covington, Tenn | 570 | 55 00 | Do. |
| Connersville, Ind | 543 | 52 00 | Too early. |
| Dale Enterprise, Va | 400 | 55 00 | Multiple of 5. |
| Dayton, Tenn | 330 | 50 00 | |
| Daytona, Fla | 277 | 25 00 | Local; multiple of 5. |
| De Land, Fla | 291 | 50 00 | |
| Delaware Breakwater, Del | 500 | 55 00 | Multiple of 5. |
| Detroit, Mich | 675 | 58 00 | Too late, and five better observations. |

*List of rejected observations*—Continued.

| Locality. | Distance. | Time. | Remarks. |
|---|---|---|---|
| | | *m. s.* | |
| Dubuque, Iowa | 878 | 62 00 | Too late. |
| Ellaville, Fla | 259 | 55 00 | Multiple of 5. |
| Fort Monroe, Va | 356 | 55 00 | Do. |
| Frankfort, Ind | 621 | 55 00 | Do. |
| Grand Haven, Mich | ........ | 48 00 | Too early. |
| Grand Junction, Tenn | 538 | 55 00 | Multiple of 5. |
| Greensborough, Ala | 435 | 60 00 | |
| Hatteras, N. C | 309 | 60 00 | |
| Indianapolis, Ind | 581 | 52 00 | Too early. |
| Jacksonville, Fla | 211 | 56 00 | Too late. |
| Jasper, Ind | 540 | 55 00 | Multiple of 5. |
| Kitty Hawk, N. C | 335 | 60 00 | |
| Knoxville, Tenn | 302 | 55 00 | Do. |
| Lake Annie, Fla | 416 | 50 00 | |
| Lancaster, S. C | 126 | 55 00 | Do. |
| Lexington, Ky | 432 | 52 41 | 9.15 local; too early and multiple of 5. |
| Lincolnton, N. C | 187 | 55 00 | Multiple of 5. |
| Louisville, Ky | 485 | 55 00 | Do. |
| Lynchburgh, Va | 316 | 50 00 | |
| Do | 316 | 55 00 | Do. |
| Madison, Ind | 500 | 52 41 | 9.15 local; too early and multiple of 5. |
| Mannington, Ky | 488 | 52 41 | Do. |
| Media, Pa | 557 | 60 00 | |
| Memphis, Tenn | 587 | 57 00 | Two to 3 minutes later than 6 other observations. |
| Do | 587 | 59 00 | Too late. |
| Milan, Tenn | 530 | 57 00 | Do. |
| Mobile, Ala | 493 | 50 00 | |
| Montgomery, Ala | 363 | 55 00 | Multiple of 5. |
| Morristown, N. J | 637 | 55 00 | Do. |
| New Castle, Ind | 566 | 55 00 | Do. |
| North Manchester, Ind | 640 | 50 00 | Do. |
| Oakland, Ill | ........ | 50 00 | |
| Oakland, Md | 455 | 55 00 | Do. |
| Orange, N. J | 642 | 55 00 | Do. |
| Orangeburgh, S. C | 58 | 48 00 | Too early. |
| Opelika, Ala | 307 | 55 00 | Multiple of 5. |
| Oswichee, Ala | ........ | 60 00 | |
| Oxford, Md | 460 | 50 00 | |
| Parkersburgh, W. Va | 448 | 55 00 | Do. |
| Pensacola, Fla | 457 | 60 00 | |
| Philadelphia, Pa | 566 | 50 00 | |
| Do | 566 | 52 00 | Too early. |
| Plainfield, N. J | 625 | 55 00 | Multiple of 5. |
| Portsmouth, Ohio | 433 | 56 00 | Too late. |
| Raleigh, N. C | 213 | 50 00 | |
| Rome, Ga | 302 | 59 00 | Probably second shock. |
| Richmond, Va | 354 | 55 00 | Multiple of 5. |
| Rutherfordton, N. C | 200 | 50 00 | |
| Sanford, Fla | 305 | 50 00 | |
| Do | 305 | 56 00 | Too late. |
| Selin's Grove, Pa | 585 | 55 00 | Multiple of 5. |
| Selma, Ala | ........ | 60 00 | |

*List of rejected observations*—Continued.

| Locality. | Distance. | Time. | Remarks. |
|---|---|---|---|
| | | *m. s.* | |
| Smithville, N. C | 137 | 50 00 | |
| Do | 137 | 54 00 | Too late. |
| Somerset, Ky | 386 | 59 00 | Do. |
| Spencer, Ind | 577 | 55 00 | Multiple of 5. |
| Sullivan, Ill | ....... | 50 00 | |
| Terre Haute, Ind | 606 | 55 00 | Do. |
| Tracy City, Tenn | 360 | 50 00 | |
| Tuscaloosa, Ala | 432 | 55 00 | Do. |
| Union Springs, Ala | ....... | 60 00 | |
| Uniontown, Pa | 487 | 55 00 | Do. |
| Valley Head, Ala | ....... | 60 00 | |
| Warsaw, N. Y | 700 | 55 00 | Do. |
| Washingtonville, N. Y | 680 | 55 00 | Do. |
| Waycross, Ga | 183 | 55 00 | Do. |
| Weldon, N. C | 281 | 50 00 | |
| Woodbury, N. J | 557 | 57 00 | To late. |
| Woodstock, Md | 502 | 55 00 | Multiple of 5. |
| Zellwood, Fla | 306 | 55 00 | Do. |

Having expurgated the list of all aberrant observations, we may now proceed to arrange the others in such a manner that each group shall consist of observations which are as nearly homogeneous as possible:

I. The first group will comprise those which meet the following requirements: (1) The report must specify the time at which the tremors first became sensible. (2) It must give not only the minutes but the seconds with an uncertainty not exceeding fifteen seconds. (3) It must have been obtained from a clock kept running with accuracy upon standard or authentic local time, or from a clock or watch which had been compared with such a regulated clock within a few hours of the occurrence.

II. The second group must fulfill the same requirements as the first, except that the report will be required to give only the nearest minute or half minute of the beginning.

III. The third group will include all accepted observations except the two groups already mentioned and the stopped clocks. These may or may not express the time of beginning. Neither is any account taken of possible errors of timepiece, which would be "accidental errors," and as the clock or watch is as liable to be too slow as it is be too fast, the mean value of the accidental error in a large number of observations would presumably be very small.

IV. The fourth group will comprise only accepted reports of clocks stopped by the first great shock. The clocks, however, must be stated to have been regulated carefully by standard time or equally good local time.

A synopsis of the entire list of observations, both those which are accepted and rejected, may now be given, with their groupings:

*Synopsis of time observations by groups.*

| | I. | II. | III. | IV. | Rejected. | Totals. |
|---|---|---|---|---|---|---|
| Earlier than $9^h\ 51^m$ | ..... | ..... | ..... | ..... | 36 | 36 |
| $9^h\ 51^m$ | ..... | ..... | 2 | 2 | 2 | 6 |
| 9 51 and seconds | ..... | ..... | 2 | 3 | 1 | 6 |
| 9 52 | ..... | ..... | 11 | 6 | 8 | 25 |
| 9 52 and seconds | ..... | ..... | 3 | 2 | 4 | 9 |
| 9 53 | ..... | ..... | 25 | 3 | ....... | 28 |
| 9 53 and seconds | 3 | 3 | 9 | 1 | ....... | 16 |
| 9 54 | 1 | 5 | 18 | 5 | 2 | 31 |
| 9 54 and seconds | 1 | 1 | 4 | 3 | ....... | 9 |
| 9 55 | ..... | 1 | 27 | 15 | 43 | 86 |
| 9 55 and seconds | ..... | ..... | 4 | 2 | 2 | 8 |
| 9 56 | ..... | 1 | 12 | 1 | 7 | 21 |
| 9 56 and seconds | ..... | ..... | 1 | 1 | ....... | 2 |
| 9 57 | ..... | ..... | 4 | 1 | 3 | 8 |
| 9 58 | ..... | ..... | 3 | ..... | 2 | 5 |
| Later than 9.58 | ..... | ..... | ..... | ..... | 20 | 20 |
| Totals | 5 | 11 | 125 | 45 | 130 | 316 |

The discussion of the time at Charleston and at the centrum has already been given. Professor Newcomb's observation is recited in his general discussion of the time reports. The observation of Sergeant Alex. McAdie was made under favorable circumstances. He noted the time of beginning by his watch, and compared it carefully with the time of the Naval Observatory the next day, and ascertained its rate, with a probable error not exceeding one or two seconds.

The observation of Mr. Randolph will be best appreciated by giving his own language. He says:

I was sitting with one leg thrown over and resting on the other. After noticing for a few seconds my suspended foot swinging at right angles with the position of my body with the regularity of a pendulum, and feeling a general movement in the same direction, and hearing a sonorous beating of some object in my bed-room adjoining keeping time with these oscillations, I arose and walked across the room to my watch, and upon inspection saw that the minute-hand was exactly half-way between $9^h\ 53^m$ and $9^h\ 54^m$. My watch has for the last two months coincided precisely with the chronometers exposed for public reference in the windows of the principal dealers, and I had made a comparison only the day before. In order to form an estimate of the duration of the phenomenon I held my watch before me, and observed the time required to repeat from memory the observations I had just made, and this indicated 45 seconds, and 10 seconds from the first sensation to the time of observations.

Although Mr. Randolph's account of the relation of his watch to accurate standard time may leave something to be desired, I am disposed to regard his observation as coming fairly within the requirements. But as the verification of his watch is subject to a somewhat larger uncertainty than that of Professor Newcomb and Sergeant

McAdie, I have given his report only half the weight assigned to the other two.

Mr. M. C. Whitney's observation at New York was indeed a happy accident. He was standing before a jeweler's fine regulator clock kept accurately to standard time, and was in the act of setting his watch, which had run down. It was a stop-watch, and he was holding the stop, waiting for the second-hand of the clock to coincide with that of his watch. While so waiting he became conscious of the disturbance, and being familiar with earthquakes he recognized the phenomenon, and at once noted the time $9^h$ $54^m$ $35^s$ by the clock. He thinks that about five seconds elapsed from the first sensation to the time of observation. Mr. Whitney's observation is strongly corroborated by a large number of reports coming from New York.

The observation of Mr. Louis Hughes, of Dyersburg, is also a good one. His watch is, "from business necessity," as he states, kept most accurately with standard time received daily at the railway station. He noted the time at $9^h$ $54^m$ $6^s$, and estimates that five or six seconds elapsed between the first sensation and the moment of observation. His watch was carefully compared next morning with the time-signal, and he gives $9^h$ $54^m$ $10^s$ as the nearest minute and second. Mr. Hughes is apparently a competent observer, and his correspondence shows that he is well aware of what is necessary to make as good an observation as the circumstances will permit.

Each of the observations constituting this group will give an equation of condition in the following manner, suggested by Professor Newcomb: The computed time of the beginning at the centrum (which has already been given) must be presumed to have some error, which may be designated by $x$. If $t_0$ be the computed time at the centrum ($9^h$ $51^m$ $6^s$) and $t$ the reported time at any other locality, then $(t-t_0)$=the number of seconds in the observed time-interval taken by the wave to travel from the centrum to the place of observation. If $D$ be the distance in statute miles and $y$ the number of seconds or fraction of a second required to travel one mile, we may form the following equation: $x+Dy=t-t_0$, in which there are only two unknown quantities, $x$ and $y$. This implies that the speed is uniform. If this implication differs widely from the truth, indications of it may be expected to appear in the residuals. It is necessary to put the equations of condition into a form in which a time and not a speed shall be the observed quantity, because the times and not the distances are the data into which the greatest uncertainty enters. If, putting $v$ for the speed of transmission, we put our equations into the form of $v\,(t-t_0)=D$, they would be subject to the objection that their uncertain quantities would be the coefficients of the unknown quantities and not the absolute terms.[1] The distances

[1] I am indebted to Professor Newcomb for this method of forming the equations of condition.

from the centrum have been taken from the Land Office map of the United States by measurement with a scale. They are subject to possible errors as great as three or four miles, but this error is so small in comparison with the best times, that the distances may be regarded as sensibly exact.

The following reports constitute the first group. For the sake of brevity the full accounts of these reports are here omitted.

GROUP I.—THE BEST OBSERVATIONS.

| Locality. | Distance. | Time $9^h$+ | Weight. | Observer. |
|---|---|---|---|---|
| | | *m. s.* | | |
| Centrum, S. C | 0 | 51 06 | 2 | |
| Washington, D. C | 452 | 53 20 | 2 | Prof. Newcomb. |
| Do | 452 | 53 23 | 2 | Alex. McAdie. |
| Baltimore, Md | 487 | 53 20 | 1 | R. Randolph. |
| New York, N. Y | 645 | 54 30 | 2 | M. C. Whitney. |
| Dyersburgh, Tenn | 569 | 54 00 | 1 | Louis Hughes. |

From these observations the following equations of condition may be formed:

| | | Weights. | Residuals. |
|---|---|---|---|
| Centrum | $x + 0\,y = 0$ | 2 | — 2.6 |
| Washington | $x + 452\,y = 135.5$ | 4 | + 1.6 |
| Baltimore | $x + 487\,y = 134$ | 1 | + 13.9 |
| Dyersburgh | $x + 569\,y = 174$ | 1 | — 0.8 |
| New York | $x + 645\,y = 204$ | 2 | — 7.3 |

The normal equations are

$$10\,x + 4154\,y = 1258$$
$$4154\,x + 2210196\,y = 672408$$

The solution gives $x = -2.6^s \pm 4.7^s$ and $y = 0.309^s \pm 0.01^s$.

The resulting speed is $3.236 \pm 0.105$ miles, or $5205 \pm 168$ meters per second.

GROUP II.—GOOD REPORTS, GIVING THE TIME OF BEGINNING TO THE NEAREST MINUTE OR HALF MINUTE.

| Locality. | Distance. | Time. | Weight. | Reported by— |
|---|---|---|---|---|
| | | *m. s.* | | |
| Centrum, S. C | 0 | 51 06 | 2 | |
| Nashville, Tenn | 438 | 53 30 | 1 | J. D. Leonard. |
| Covington, Ky | 488 | 53 41 | 1 | Joseph Brookshaw. |
| Pikesville, Md | 490 | 53 30 | 1 | C. R. Goodwin. |
| Evansville, Ind | 545 | 54 00 | 1 | F. W. Norton. |
| Cleveland, Ohio | 604 | 54 00 | 1 | William Line. |
| Do | 604 | 54 00 | 1 | G. H. Tower. |
| Crawfordsville, Ind | 620 | 54 00 | ½ | E. C. Simpson. |
| Belvidere, N. J | 622 | 54 00 | 1 | G. W. Holstein. |
| New York, N. Y | 645 | 54 30 | 1 | New York Herald. |
| Stockbridge, Mass | 765 | 56 00 | ½ | J. O. Jacot. |
| Albany, N. Y | 770 | 55 00 | 1 | W. G. Tucker. |

1. The report of Mr. Leonard, of Nashville, states that he was sitting in his office at the time of the earthquake. A large clock, with

a pendulum beating seconds and with a second-hand, was fastened to the wall in front of him. It is from business necessity regulated most carefully to standard time. The time was noted within a very few seconds of the beginning as almost exactly $9^h\ 53^m\ 30^s$. The clock subsequently stopped by the pendulum beating against the door of the clock-case at $9^h\ 54^m\ 12^s$.

2. The report of Mr. Joseph Brookshaw, of Covington, Ky., has been carefully inquired into. He had become familiar with earthquakes by a residence of several years in San Francisco, and recognized the nature of the tremors at once, and knew the importance of noting the time with accuracy. Some delay occurred in getting his watch, but he estimated the time which elapsed between the first sensation and the reading of his watch as being very nearly twenty seconds. The next morning he compared his watch with the regulator of I. J. Evans, and, after correcting for the error of his watch, gives the time as $9^h\ 16^m$ local or $9^h\ 54^m\ 41^s$ standard for the beginning. He believes his error will not exceed ten seconds. The regulator of Mr. Evans is controlled by Duhme & Co., of Cincinnati, who furnish exact time for that city and suburban towns. This clock also stopped at a later phase of the disturbance, viz, $9^h\ 17^m\ 20^s$ local or $9^h\ 55^m$ standard.

3. At Pikesville, Md., near Baltimore, Mr. C. R. Goodwin noted the time at the close of the first maximum at $9^h\ 54^m$. By comparison with the time-ball in Baltimore the next day he found his watch half a minute slow. As the time from the beginning to the close of the first maximum in Washington and Baltimore is known to have been very nearly one minute, the correction for Mr. Goodwin's report gives $9^h\ 53^m\ 30^s$ as the time of the beginning.

4. Mr. F. W. Norton was in a third-story room of a hotel in Evansville, and had just noted the time by his watch as $9^h\ 57^m$. At that instant he became aware of an unusual disturbance and shaking of the room, accompanied by a strange sensation of unsteadiness, and soon realized that it was an earthquake. A few minutes afterward he went downstairs, and, during a discussion of the subject, there was some difference of opinion as to the time. To settle the matter he went to the telegraph office, and found his watch $2^m\ 55^s$ fast; this making the time very nearly $9^h\ 54^m$ for the beginning.

5. The report from William Line, Signal Service observer at Cleveland, gives $9^h\ 54^m$ for the beginning, his clock being carefully regulated to standard time.

6. The report of G. H. Tower, keeper of the light-house, gives $9^h\ 54^m$ as the time of beginning. In this instance the light-house keeper had ample facilities for securing accurate standard time. He states that his clock was compared the next day.

7. The report of E. C. Simpson, of Crawfordsville, states that as soon as he felt the tremors he recognized their character, and instantly noted his watch, which, as shown by comparison with the time at the railway station, was correct. As Mr. Simpson's report

does not state how soon his watch was compared with standard time, or even whether it was compared before or after, it is given only one-half the weight of the others.

8. Mr. G. W. Holstein, of Belvidere, N. J., noted the time at the beginning, or within a very few seconds of it, as $9^h\ 54^m$, and the tremors continued until $9^h\ 59^m$. He compared his watch carefully the next morning with the time of the Pennsylvania Railroad.

9. The New York Herald reports that the shock was felt in the main office of the Western Union Telegraph Company in New York City with unusual severity. One of the operators in the upper part of this great building was sending a telegram, and, in accordance with the regular practice, had marked upon it the minute at which it was sent, $9^h\ 54^m$. Just as he finished sending it he, in common with all the other operators in the room, became aware of the tremors. He gives the time as $9^h\ 54^m\ 30^s$ for the beginning. The Herald does not give the name of the operator, but as the report is sufficiently circumstantial, and as this office is the proximate source of accurate standard time for the most populous portion of the United States, it is accepted at face value. It agrees well with the tenor of a large number of reports from New York City, and especially with the excellent report of Mr. M. C. Whitney, in the first group.

10. From Stockbridge, Mass., Mr. J. O. Jacot reports that he was favorably situated for observation. He is a jeweler, and was sitting beside his regulator at the time. The tremors were quite faint, but were distinctly noted. He gives the time of beginning by his clock as $9^h\ 56^m$. As it is quite probable that he failed to recognize the earlier tremors, and as his observation is considerably aberrant, it is given only half weight.

11. Dr. W. F. Tucker, of Albany, N. Y., felt the tremors very distinctly, and noted the time at once. He compared his watch next morning with the time of the Dudley Observatory, and after correction for its error he gives the time of beginning as $9^h\ 55^m$, with an uncertainty not exceeding twenty seconds. The tremors were much more sharply defined at Albany, according to all accounts, than at Stockbridge.

From these observations we may form the following equations of condition:

| | Distance. | Weights. | Residuals. |
|---|---|---|---|
| Centrum ........ | $x + 0\,y = 0$ | 2 | $-1.6$ |
| Nashville ........ | $x + 438\,y = 144$ | 1 | $-9.8$ |
| Covington ....... | $x + 488\,y = 155$ | 1 | $-5.3$ |
| Pikesville ........ | $x + 490\,y = 144$ | 1 | $+6.3$ |
| Evansville ....... | $x + 545\,y = 174$ | 1 | $-6.6$ |
| Cleveland ........ | $x + 604\,y = 174$ | 2 | $+11.6$ |
| Crawfordsville ... | $x + 620\,y = 174$ | $\frac{1}{2}$ | $+16.6$ |
| Belvidere ........ | $x + 622\,y = 174$ | 1 | $+17.2$ |
| New York ...... | $x + 645\,y = 204$ | 1 | $-5.6$ |
| Stockbridge ...... | $x + 765\,y = 294$ | $\frac{1}{2}$ | $-58.4$ |
| Albany .......... | $x + 770\,y = 234$ | 1 | $+3.1$ |

The normal equations are—

$$12\ x + 5898.5y = 1811$$
$$5898.5\,x + 3577366.5\,y = 1100677$$

The solution gives $x = -1.6^s \pm 7.7^s$ and $y = 0.310^s \pm 0.014^s$. The resulting speed is $3.226 \pm 0.147$ miles, or $5192 \pm 236$ meters per second.

GROUP III.—MISCELLANEOUS OBSERVATIONS.

This group contains all accepted observations which remain after deducting those comprised in Groups I and II, already discussed, and the stopped clocks. There are a few of them which state that the time given is that of the beginning of the tremors, but they fail to give any assurance that the clock or watch was in close agreement with authentic time. Very many of them assert that the clock or watch was right, but fail to state that the time given was that of the beginning. It is quite probable that many good observations are contained in this group; as good as, and perhaps even better than, some of those contained in the first two groups. But they are unaccompanied by the evidence which is necessary to entitle them to so much credit. It is also probable that many of them refer to advanced phases of the earthquake. Thus it must appear that this group as a whole ought to give a lower speed or later mean time of observation than the two preceding ones. It is not possible that, apart from the errors of clocks or watches, any observer would report a time earlier than the beginning; but many might note a phase later than the beginning. Hence the personal errors of observation are on the whole almost sure to be in one direction, and that is towards a time later than the beginning. It is therefore a systematic error, which is not eliminated by taking the mean or average. There is no satisfactory means of estimating the magnitude of this systematic error. How large a proportion of the observers would seek to identify the observed time with that of the beginning it is impossible to judge. In localities at a great distance from the centrum, six hundred and fifty miles or more, where the tremors were so light that only those who were favorably situated perceived them at all, and where the beginning was very gradual, it might be anticipated that even the most intelligent observers would fail to recognize them until many precious seconds had passed, and would be quite unable to identify the beginning at all. The general indications are, however, that this systematic error is not a very large one; and, in fact, that it is smaller than might at first be anticipated. For example: We have from three cities a considerable number of closely concordant reports, viz, Washington, New York, and Cincinnati, some of which distinctly state the time of beginning as ascertained by verified clocks or watches, while others do not state the phase at all. In Washington the mean of reports is twelve or fifteen seconds later than the excellent reports of Professor Newcomb

and Sergeant McAdie. In New York the mean of observations is fifteen seconds earlier than the two reports which give the time of the beginning. In Cincinnati the mean of all reports is about fifteen seconds later than the beginning. On the whole the average observer must be credited with a good deal of common sense, and in a large proportion of the cases I infer that he honestly endeavored to report the beginning. The chief difficulty was in recognizing the beginning in places where the tremors were comparatively light. The systematic error which would arise from this cause is probably small. It seems to me that it ought not to be estimated as greater than one-tenth of the time interval between Charleston and the place of observation, nor less than one-twentieth of that amount.

GROUP III.—LIST OF ONE HUNDRED AND TWENTY-FIVE MISCELLANEOUS TIME REPORTS, EXCLUDING ALL OF GROUPS I, II, AND IV.

| Locality. | Distance. | Time. | Weight. | Remarks. |
|---|---|---|---|---|
| | | *m. s.* | | |
| Statesburgh, S. C | 80 | 51 30 | 1 | |
| Columbia, S. C | 89 | 52 00 | 1 | |
| Savannah, Ga | 89 | 51 53 | 2 | Three reports. |
| Augusta, Ga | 111 | 51 30 | 2 | Two reports. |
| Laurinburgh, N. C | 135 | 1 00 | 1 | |
| Darien, Ga | 138 | 52 30 | 1 | |
| Brunswick, Ga | 155 | 52 00 | 1 | |
| Macon, Ga | 203 | 52 00 | 1 | |
| Jacksonville, Fla | 211 | 52 00 | 2 | Three reports. |
| Fernandina, Fla | 225 | 53 00 | 1 | |
| Olustee, Fla | 255 | 53 00 | 1 | |
| Palatka, Fla | 255 | 53 00 | 1 | |
| Thomasville, Ga | 273 | 52 20 | 1 | |
| Wytheville, Va | 284 | 52 37 | 1 | |
| Knoxville, Tenn | 302 | 54 00 | 1 | |
| Zellwood, Fla | 306 | 53 00 | 1 | |
| Chattanooga, Tenn | 329 | 53 00 | 1 | |
| Norfolk, Va | 349 | 54 00 | 1 | |
| University, Ala | 363 | 52 00 | 1 | |
| Ashland, Va | 367 | 52 00 | 1 | |
| Shelby Iron Works, Ala | 377 | 54 00 | 1 | |
| Catlettsburgh, Ky | 405 | 52 30 | 1 | Two reports. |
| Pungoteague, Va | 410 | 53 00 | 1 | |
| Decatur, Ala | 412 | 53 00 | 1 | |
| Ironton, Ohio | 414 | 55 00 | 1 | |
| Nashville, Tenn | 438 | 54 30 | 1 | |
| Washington, D. C | 452 | 53 41 | 2 | Four reports. |
| Louisville, Ky | 485 | 54 38 | 1 | Two reports. |
| Baltimore, Md | 487 | 53 00 | 1 | |
| Dayton, Ky | 487 | 54 11 | 1 | |
| Newport, Ky | 488 | 53 21 | 1 | |
| Cincinnati, Ohio | 491 | 53 41 | 4 | Six reports. |
| Lancaster, Ohio | 491 | 54 00 | 1 | |
| Wyoming, Ohio | 501 | 53 41 | 1 | |
| Columbus, Ohio | 513 | 53 41 | 2 | Four reports. |
| Hamilton, Ohio | 513 | 54 11 | 1 | |
| Paris, Tenn | 520 | 56 00 | 1 | |

GROUP III.—LIST OF ONE HUNDRED AND TWENTY-FIVE MISCELLANEOUS TIME REPORTS, INCLUDING ALL OF GROUPS I, II, AND IV.—Continued.

| Locality. | Distance. | Time. | Weight. | Remarks. |
|---|---|---|---|---|
| | | m. s. | | |
| Pittsburgh, Pa | 525 | 54 30 | 1 | Two reports. |
| Brookville, Ind | 526 | 53 00 | 1 | |
| New Philadelphia, Ohio | 532 | 54 00 | 1 | |
| Sewickley, Pa | 535 | 54 00 | 1 | |
| Mount Vernon, Ohio | 536 | 56 00 | 1 | |
| Wellsville, Ohio | 538 | 55 00 | 1 | |
| Oxford, Miss | 548 | 56 00 | 1 | |
| Paducah, Ky | 558 | 52 15 | 1 | |
| Philadelphia, Pa | 566 | 53 00 | 1 | |
| Burlington, N. J | 584 | 53 00 | 1 | |
| Indianapolis, Ind | 584 | 55 00 | 2 | Two reports. |
| Cairo, Ill | 588 | 53 00 | 1 | |
| Titusville, Pa | 608 | 56 00 | 1 | |
| Helena, Ark | 609 | 55 00 | 1 | |
| Toledo, Ohio | 637 | 55 00 | 1 | |
| Newark, N. J | 640 | 53 00 | 1 | |
| Jamestown, N. Y | 642 | 56 00 | 1 | |
| Brooklyn, N. Y | 643 | 54 30 | 3 | Four good reports. |
| New York, N. Y | 645 | 54 12 | 6 | Ten reports. |
| Hackensack, N. J | 654 | 54 00 | 1 | |
| Warwick, N. Y | 661 | 56 00 | 1 | |
| Gowanda, N. Y | 666 | 55 00 | 1 | |
| Detroit, Mich | 675 | 55 12 | 3 | Five reports. |
| Valparaiso, Ind | 705 | 53 00 | 1 | |
| London, Ontario | 706 | 55 00 | 1 | |
| Peoria, Ill | 710 | 55 00 | 1 | |
| New Haven, Conn | 711 | 55 30 | 2 | Two reports. |
| Port Huron, Mich | 712 | 55 00 | 1 | |
| Hudson, N. Y | 747 | 57 00 | 1 | |
| Hartford, Conn | 747 | 54 45 | 2 | Two reports. |
| Stuyvesant, N. Y | 760 | 57 00 | 1 | |
| East Saginaw, Mich | 766 | 58 00 | 1 | |
| Albany, N. Y. | 770 | 56 40 | 1 | |
| Fonda, N. Y | 775 | 55 00 | 1 | |
| Saratoga, N. Y | 797 | 53 00 | 1 | |
| Greenfield, Mass | 799 | 55 00 | 1 | |
| Keokuk, Iowa | 810 | 56 00 | 2 | Two reports. |
| Dighton, Mass | 812 | 56 00 | 1 | |
| Davenport, Iowa | 827 | 55 00 | 1 | |
| Lake Placid, N. Y | 827 | 55 00 | 1 | |
| Jamaica Plain, Mass | 828 | 57 00 | 1 | |
| Blue Mountain Lake, N. Y | 830 | 56 00 | 1 | |
| Bellows Falls, Vt | 832 | 53 00 | 1 | |
| Boston, Mass | 832 | 55 30 | 1 | Two reports. |
| Dubuque, Iowa | 878 | 57 00 | 1 | |
| Prairie du Chien, Wis | 924 | 56 30 | 1 | |

Let us take these observations in sets, the first comprising those within 200 miles of the centrum, the second those between 200 and and 300 miles, the third those between 300 and 400 miles, and so on until the last, which shall comprise all beyond 800 miles. If we

take the weighted arithmetical mean of each of these sets we shall have the following equations of condition, in which $x =$ the time of beginning, less $9^h\ 51^m\ 6^s$, and $y =$ the fraction of a second occupied by the wave in going one mile:

| | | Weights. | Residuals. |
|---|---|---|---|
| | $x + 0\,y = 0$ | 2 | + 4.06 |
| 0 to 155 | $x + 111\,y = 39$ | 9 | + 1.90 |
| 203 to 284 | $x + 240\,y = 84$ | 8 | − .28 |
| 302 to 377 | $x + 342\,y = 122$ | 7 | − 4.43 |
| 405 to 491 | $x + 462\,y = 158$ | 16 | − .60 |
| 501 to 588 | $x + 542\,y = 184$ | 18 | − .05 |
| 608 to 675 | $x + 647\,y = 217$ | 20 | + 1.80 |
| 705 to 799 | $x + 744\,y = 255$ | 15 | − 4.00 |
| 810 to 924 | $x + 837\,y = 278$ | 11 | + 3.85 |

The normal equations are:

$$106\,x + 55768\,y = 18940$$
$$55768\,x + 34474772\,y = 11668675$$

The solution gives $x = + 4.06 \pm 1.7^s$ and $y = 0.3319 \pm 0.0029^s$. The resulting speed is $3.013 \pm 0.027$ miles, or $4848 \pm 43$ meters. To this result, however, must be applied a correction for the systematic error, which we have taken to be one-fifteenth of the result. The probable error of this correction is no doubt a relatively large one, because of the uncertain grounds upon which it is estimated. I shall take it to be one-third of the correction. This will make the corrected result $3.214 \pm 0.072$ miles, or $5171 \pm 116$ meters per second.

### GROUP IV.—STOPPED CLOCKS.

It is natural to suppose that if a clock were stopped by an earthquake, and if its error at the time were known, it would give the best possible record of the time of advent of the shock. An examination of the time reports of this earthquake, however, strongly contradicts this conclusion. A clock may stop at almost any phase of the disturbance. A sensitive one may pass through an earthquake of considerable violence and not stop at all. A jeweler's clock in Charleston was found going the next morning, and when the telegraph wires were reopened its error was found to be small, showing that its escapement had missed very few beats, if any. Clocks in Columbia, Savannah, Augusta, and Wilmington, N. C., in many cases kept going. Inquiry at Wilmington elicited the reply that no jewelers' clocks had been stopped. Several reports describe clocks whose rates are satisfactorily vouched for, but whose times can be accounted for only upon the theory that they were stopped by the second powerful shock, which was felt at Charleston about five minutes after the principal one; e. g., Branchville, S. C.; Augusta and Rome, Ga.; Cape Canaveral; Camden, Ala.; Memphis, Tenn. There are some cities where the time of beginning is well established by independent observation and which also report stopped clocks. In every such case the time of the stopped clock is much later. Thus at Nashville the time of beginning was noted by a clock which continued going for forty-two seconds and then stopped. Similar means of comparison come

from Cincinnati; Covington, Ky.; Pittsburgh; Newark, N. J.; Brooklyn, and New York. And, in general, wherever stopped clocks can be compared with really good personal observations they invariably show a later time, and usually a much later one. The difference is plainly due to the fact that it generally takes a considerable time and an accumulation of the effects of the vibrations of the building upon the pendulum to stop a clock. An attempt has been made to evaluate this difference by taking those cases where a comparison can be made between the readings of stopped clocks and independent determinations of the times of the beginning in the same locality.

| Locality. | Intervals by personal observations. | Intervals by stopped clocks. | Ratios. | Weights. |
|---|---|---|---|---|
| | *Seconds.* | *Seconds.* | | |
| Nashville, Tenn | 144 | 186 | 1.29 | 2 |
| Covington, Ky | 155 | 235 | 1.52 | 1 |
| Cincinnati, Ohio | 155 | 195 | 1.26 | 2 |
| Pittsburgh, Pa | 174 | 234 | 1.34 | 1 |
| Brooklyn, N. Y | 204 | 234 | 1.15 | 1 |
| New York, N. Y | 204 | 249 | 1.22 | 2 |
| Mean ratio | | | 1.28 | |

In this table the comparison at Cincinnati takes account only of a single clock, whose error happened to be known exactly. The time of beginning in that city is also known with exceptional certainty and accuracy. It will not differ more than eight or ten seconds from $9^h\ 16^m$ Cincinnati local mean time, or $9^h\ 53^m\ 41^s$ standard time. If we consider Cincinnati and suburban towns within 15 miles of the city which are supplied with local time from the Cincinnati Observatory, we have no less than twenty-two time reports, of which nine are stopped clocks. Two personal observations giving $9^h\ 15^m$ local have been rejected, because they are multiples of five. One report giving $9^h\ 17^m\ 45^s$ has been rejected because its author, besides indicating that it refers to an advanced phase, throws doubt on his own observation. Of the remaining ten personal observations one gives $9^h\ 15^m\ 40^s$, eight give $9^h\ 16^m$, and one gives $9^h\ 16^m\ 30^s$. Of the stopped clocks, three were in the central office of the Western Union Telegraph Company. They kept standard time, and were read only to the nearest minute. All three are reported to have stopped at $9^h\ 54^m$. The clock in the fire tower is the one whose error was known. Its corrected reading was $9^h\ 16^m\ 40^s$. The remaining clocks gave $9^h\ 15^m$, $9^h\ 16^m$, $9^h\ 17^m$, $9^h\ 17^m\ 20^s$, and $9^h\ 19^m$. Four of the latter were from the surburban town of Lockland. Reducing to standard time and taking their mean, the ratio of the time-interval by stopped clocks to that by personal observation is $1^h\ 26^m$, a result identical with that derived from the clock in the fire tower and nearly the same as that in the table. There is reason to believe, however, that this ratio is a little too great for the mean of stopped

clocks throughout the entire country, and especially so for those of very distant localities; for if the ratio were uniform, the absolute differences between the two kinds of data would be very wide in remote regions and small near the centrum. This is not the case. The absolute differences at very remote localities are very little, if any, greater than those at the middle distances. This difficulty prevents us from assigning any specific value to the correction and from determining its probable error. Nevertheless the comparisons just made indicate that the systematic error is probably of such magnitude that, if due allowance were made for it, the corrected result for the stopped clocks would not differ much from those of the preceding groups. While this group furnishes evidence which strongly supports the approximate correctness of the results of the other three, it can not be a source of greater precision nor can it furnish the means of reducing the final probable error.

STOPPED CLOCKS.

| Locality. | Distance. | Time. | No. of clocks. | Weight. |
|---|---|---|---|---|
| | | *m. s.* | | |
| Centrum, S. C | 0 | 51 06 | ........ | ........ |
| Charleston, S. C | 20 | 51 12 | 4 | 3 |
| Columbia, S. C | 89 | 51 00 | 2 | 2 |
| Savannah, Ga | 89 | 51 55 | 2 | 2 |
| Langley, S. C | 103 | 53 00 | 1 | 1 |
| Augusta, Ga | 111 | 52 00 | 1 | 1 |
| Cochran, Ga | 192 | 52 00 | 2 | 2 |
| Macon, Ga | 203 | 51 30 | 1 | 1 |
| Jacksonville, Fla | 211 | 52 00 | 1 | 1 |
| Atlanta, Ga | 252 | 52 22 | 4 | 3 |
| Catlettsburgh, Ky | 405 | 53 00 | 1 | 1 |
| Nashville, Tenn | 438 | 54 12 | 1 | 1 |
| Columbus, Miss | 481 | 56 00 | 1 | 1 |
| Covington, Ky | 488 | 55 00 | 1 | 1 |
| Cincinnati, Ohio | 491 | 54 00 | 3 | 2 |
| Do | 491 | 54 21 | 1 | 1 |
| Meridian, Miss | 500 | 54 00 | 1 | 1 |
| Lockland, Ohio | 505 | 54 26 | 4 | 3 |
| Havre de Grace, Md | 515 | 55 00 | 1 | 1 |
| Pittsburgh, Pa | 525 | 55 00 | 1 | 1 |
| New Castle, Del | 538 | 54 00 | 1 | 1 |
| Atlantic City, N. J | 552 | 54 00 | 1 | 1 |
| Wooster, Ohio | 558 | 55 45 | 1 | 1 |
| New Castle, Pa | 565 | 55 00 | 1 | 1 |
| Indianapolis, Ind | 581 | 55 00 | 1 | 1 |
| Memphis, Tenn | 587 | 54 50 | 6 | 4 |
| Cairo, Ill | 588 | 53 00 | 1 | 1 |
| Meadville, Pa | 608 | 55 00 | 1 | 1 |
| Newark, N. J | 640 | 55 00 | 1 | 1 |
| Brooklyn, N. Y | 643 | 55 00 | 1 | 1 |
| New York, N. Y | 645 | 55 15 | 2 | 1 |
| Ithaca, N. Y | 696 | 55 00 | 1 | 1 |
| Manistee, Mich | 855 | 57 00 | 1 | 1 |

We may arrange these in groups or sets according to their distances, as was done in the discussion of Group III, and obtain the following equations of condition:

| Miles. | | Weight. | Residuals. |
|---|---|---|---|
| 0 to 89 | $x + 59\,y = 15$ | 7 | $+12.29$ |
| 103 to 192 | $x + 150\,y = 69$ | 4 | $-7.21$ |
| 203 to 252 | $x + 234\,y = 110$ | 5 | $-16.37$ |
| 405 to 491 | $x + 469\,y = 194$ | 7 | $-11.29$ |
| 500 to 588 | $x + 594\,y = 209$ | 16 | $+4.04$ |
| 608 to 696 | $x + 642\,h = 237$ | 5 | $+12.80$ |
| 855 | $x + 855\,y = 354$ | 1 | $-24.97$ |

The normal equations are:

$$\begin{aligned} 45\,x + 183315\,y &= 7172 \\ 18335\,x + 9567895\,y &= 3717233 \end{aligned}$$

From which $x = +5.0$, $y = 0.379$. The resulting speed is $2.638 \pm 0.105$ miles, or $4245 \pm 168$ meters per second. If the correction for the systematic error has a value approximately that which has been derived from the comparisons of the stopped clocks with well-determined times of particular localities, or not less than one-fifth the amount, the corrected speed would be from 5,100 to 5,200 meters.

### RÉSUMÉ.

We may now proceed to combine the results of the first three groups and obtain from them a single mean. The probable error of the fourth group being uncertain, it is necessary to omit it. Taking the weights inversely as the squares of the probable errors, we have:

| | | Weight. |
|---|---|---|
| Group I | $5205^{m} \pm 168^{m}$ | 2 |
| Group II | $5192^{m} \pm 236^{m}$ | 1 |
| Group III | $5171^{m} \pm 116^{m}$ | 4 |
| Mean result | $5184^{m} \pm 80^{m}$ | |

It remains to inquire whether the data indicate any variation of the speed. The answer is negative. The data are inconsistent with any variation of a systematic character, and there is no apparent means of detecting an unsystematic one. A small irregular variation, such as might be caused by varying density and elasticity of the propagating medium, would not be inconsistent with the data; but the evidence of it can not be separated from errors of observation. If it be asked whether the speed thus indicated was uniform in all directions, the reply is affirmative, though small differences of speed in different directions might be possible. But such differences are surely within limits which are explicable by errors of observation.

This speed so much exceeds any result hitherto obtained, that some critical remarks may be indulged in. A careful examination of the data will show that their general accuracy and intrinsic weight must far exceed those obtained from any preceding earthquake; and there are several excellent reasons why they should be so. First, there is the wide extent of country over which the shocks were felt. The great earthquakes of the last two centuries have not often occurred

in countries inhabited by people who are careful observers of time or who have abundant means of observing it. Most of them have happened in Asia, in the East India Islands, in South America, and in the West Indies. Those which have visited the Mediterranean have seldom made themselves felt more than three or four hundred miles from their origins, and of those which have been appreciable at greater distances it is certain that no good time intervals are on record. Second, the country affected by the Charleston earthquake is well filled by a people who are in the habit of noting time. Third, and far more significant than all, is the universal use of the standard time system. It matters little how numerous the time observations may be if there is no check upon their accuracy, no governing source and control of the time. Until recently the United States was the only country where any such check or means of control was employed. The supposition would be by no means extravagant that the number of clocks in the United States whose errors are less than two minutes is ten times greater since the adoption of the standard time system than it was before. The time-keeping of the people at large before the adoption of the standard system was doubtless as good as that of any other people. Since its adoption the time-keeping has been immeasurably improved.

In other earthquakes the only time data which seem to me worthy of a moment's consideration are those obtained from astronomical clocks, or from clocks which were regulated by astronomical sources in a most careful and unusual manner. Such clocks, even in western Europe, must have been exceedingly rare until within the last twenty-five years, or within such time as the use of the telegraph has become universal. I am disposed therefore to reject as of no value all estimates of the speed of earthquakes made prior to 1865. The experience gained in dealing with the time data of the Charleston earthquake has satisfied me that no single observation can be trusted to give a result with a probable error less than the result itself. Observations which seem to fulfill all the demands of technical evidence, made by persons whose intelligence and veracity no one would presume to question, and circumstantial in every material respect, are frequently found to be hopelessly inconsistent with each other. Only when taken in large numbers and subjected to the corrections by least squares do any consistent and satisfactory results appear. The great strength and highly convincing character of the Charleston data consist in the large number of observations and the small range of error arising from the use of the standard time system. After a careful study of the estimates made of the speed of propagation in other earthquakes, I have no hesitation in expressing the belief that all others that have ever been made and published hitherto possess much less weight than the data obtained from the Charleston earthquake.

Another circumstance which lends additional weight to the result is the approximate agreement of the deduced speed with that which theory indicates as belonging to the movement of elastic waves in an indefinitely extended solid mass of siliceous material. Although the number of experimental measurements of the coefficients of elasticity in the siliceous or glassy materials is not so great as is desirable, enough of them have been made to indicate pretty decisively the limits within which these elasticities (and consequent speeds of wave motion) vary. These speeds for normal waves must range from 15,500 to 18,000 feet per second in siliceous material, and of such material we have good reason to believe the earth is composed within a hundred miles at least of its surface. Thoroughly compact and continuous by reason of vast pressure, these deeply buried layers transmit the energy of the shock with little loss and with a speed differing not appreciably from that due to their elasticity and density.

The experimental measurements of the speed of artificial tremors in the ground made by Mallet, and again by Milne, in Japan, are not comparable with the true earthquake. It is not to be expected that the superficial layers of the earth will transmit the waves with so high a speed as the deeper layers; for their elasticity must be very much less. Indeed, we should not be surprised to find the speed in unconsolidated or discontinuous material many times smaller, as the measurements of Mallet and Milne seem to indicate.

## CHAPTER VIII.

### THE NATURE AND MECHANISM OF WAVE MOTION.

As this work is designed for a larger class of readers than those who have made earthquakes a special subject of investigation, it is thought fitting to write a chapter or two upon the nature of earthquake movements as viewed in the light of theoretical science. The subject is a difficult one to present in such a manner as to be intelligible to general readers of science, but an attempt to render it so will be made.

In common parlance, the impulses which proceed from a center of seismic disturbance are spoken of as waves. The same word is used in the same sense by the scientific investigator. Similarly, the motions of water are called waves; and we speak of sound as waves in the air; or of light as waves in a conjectural medium filling all space. These phenomena differ widely from each other in many respects. What have they in common which warrants a common name?

The only kind of wave motion which is presented to our consciousness is in the form of a visible image; in other words, the only instances in which we see a body of matter in the act of undulating are waves in liquids. With these every one is familiar. But the waves of the air which result in sound, the waves of the ethereal medium which produce light, are never seen in the sense in which we see the waves of the ocean. They are inferred by reason only. It is so with the true earthquake wave. It is never seen, however powerfully it may be felt. Those visible waves of the surface of the ground which have been so frequently testified to in Charleston and in other great earthquakes are not the waves which the seismologist has in mind, though they must of course be secondary effects of them.

The waves which we see in water differ greatly in their nature from the sound waves in the air and from those of the earth which constitute the earthquake. The forces called into play and the motions set up in the waving masses are very different. Let us first consider the wave upon the surface of a body of water. If a pebble be dropped into a smooth pool or lake the water is displaced. Being driven away from the immersing stone, it escapes in the direction of lines of least resistance. These lines are obliquely upwards around the periphery of the pebble. The result is that a circlet of water is

raised around the pebble as it is being immersed. The force of terrestrial gravitation is at once called into action, and tends to restore the water to its original level. The motion of each particle of water thereafter is the resultant of two forces; that derived from the original impulse, and the force of gravitation. It will be seen by a moment's reflection that the action of the original impulse is outwards, or radially away from the center of impulse, and the particles of water are impelled against other particles outside of the ring of disturbance. Thus the impulse is propagated ever outwards and away from the origin.

The sound wave is of a different nature. This would be suggested at once by the fact that the water wave just described is a phenomenon affecting the surface, and those layers of water near the surface, of the pool; while the sound wave affects the air in every direction, and equally at equal distances from the origin. The force called into action is not gravitation, but the elastic force of the air itself. The vibrating reed, which may for instance be the first source of the sound, imparts motion to the particles of air in contact with the reed, producing a slight compression in an envelope of surrounding air. This compression increases the elastic force or tension of the air, which reacts upon the reed and also upon the second envelope surrounding the first. The second envelope acts upon the third, and so on indefinitely. But it is desirable to consider in some detail the essential characteristics of sound waves in air, because they embrace in a simpler form certain motions which are presented in a more complex form by waves in solid bodies, of which earthquake tremors are examples.

Of the various concepts which may be formed of the ultimate constitution of matter, that one which regards it as consisting of particles separated by equal or symmetrical intervals and held in their relative positions by forces inherent in the particles themselves sufficiently meets the present requirements. So far as regards fluids, these inherent forces may be considered as mere repulsions, the intensity of which diminishes as the distance between particles increases. Upon these assumptions, suppose the air to be acted upon by a vibrating reed: The particles of air in contact with the advancing side of the reed are suddenly projected towards the adjacent particles outside of them. In consequence of the property of inertia inherent in all matter, the distance between two consecutive layers of air is diminished and the repulsive forces between them correspondingly increased. But the increased force, acting upon the second layer, drives it towards the third, thus advancing or propagating the disturbance from layer to layer indefinitely.

But as the increased repulsive force due to the diminished interval tends to repel the second particle, so also by reaction does it tend to retard the forward motion of the first particle, bringing it to rest or

perhaps driving it back to its original place. In any event the change of interval is momentary and the original interval is quickly resumed. Two cases may be considered, one of which is unreal, though in a certain sense imaginable, the other real or actually occurring in nature. The unreal case may be discussed in order to render the real case more clear.

If the second particle be conceived of as being held rigidly in its place while the first particle is impelled towards it, the reaction or elastic force would drive the latter back through and beyond its original position. Imagining a third particle situated as far to the left of the initial position of the first particle as the second is to the right of it; also imagining this third particle to be incapable of displacement, then the recoil of the first particle through its original position towards the third would produce a second elastic reaction symmetric with, but in inverse direction to, the first. Thus, under the conditions supposed, the first particle, once displaced, would continue to vibrate back and forth forever. But if the second particle, instead of being held rigidly in place, is free to move under an impulse in the same way as the first, the elastic reaction will simply drive the first particle back to its initial position, where it will come to final rest. The second particle will perform a single oscillation like the first and also come to rest; but in respect to time its movements will be a little later than those of the first, though repeating them phase by phase. Similarly also the third, fourth, and remoter particles; but in proportion as any particle is more and more remote from the first, in the same proportion will its movements, though similar in configuration, be later in respect to time.

Conceive now a remote particle so situated that when the first particle has just completed its oscillation the remote one has just received the transmitted impulse, and therefore has just begun its oscillation. The distance between such a particle and the first constitutes a wave length. The rectilinear distance which measures the extreme displacement of any one particle is called its amplitude. A wave may have any wave length great or small or any amplitude, and both of these quantities will depend mainly upon the nature of the originating impulse.

But in any one homogeneous medium the rate of propagation of an elastic wave will be (subject to a qualification to be men ioned) uniform for all amplitudes and all wave lengths. This important fact is demonstrated by experiment, but the theoretical explanation of it can be made intelligible only by the aid of mathematical analysis and only to those who are thoroughly familiar with the fundamental laws of force and motion. In general terms, however, it may be said that the speed with which an impulse is propagated through an elastic medium depends upon two properties: First, the elasticity of the medium or degree of force which its particles exert upon each other.

Second, the resistance which by virtue of their inertia the particles offer to the reception of impressed motions. But since the inertia of a particle is proportional to its mass, and since the density of a given volume of matter is also proportional to the mass of its particles, we may substitute density for inertia, and say that the rate of propagation is dependent upon the elasticity directly and upon the density inversely. The law deduced by theory and confirmed by experiment is that the rate of propagation is proportional to the square root of the quotient of elasticity divided by density. For ordinary sound vibrations this quotient is very nearly constant. But it is not strictly so. An impulse producing a compression of the medium also generates heat, which causes an additional increase of elastic force among the particles subject to compression, and this tends to increase the rate of propagation. But in sounds of moderate intensity the increment of elastic force by heat usually bears a very small ratio to the original elasticity, and it is only when the impulses and resulting compressions are of considerable magnitude that they produce a sensible increase of the rate of propagation.

A wave in an elastic fluid is propagated in all directions away from its origin. It is the continuously expanding locus of movement among the particles of the medium. Its form is a spherical shell surrounding its origin as a center. The thickness of this shell is the wave length. The distance to and fro which any particle of this shell traverses is the amplitude. As the spherical shell, including the wave, expands, its thickness, and therefore the wave length, remains the same, but the amplitude diminishes in the same ratio that the radius of the shell increases.

The direction of motion of any particle subject to the wave is coincident with the direction of propagation, i. e., to and from the origin of the wave. In a fluid medium that particle cannot vibrate transversely to the direction of propagation; for the force which determines the motion of a particle, $a$, arises from the compression of the medium within the shell, causing a greater degree of elasticity than exists without the shell. The difference of the two elasticities is the motive force, whose direction must be from the greater towards the less; but in the directions from $a$ to $b$ and from $a$ to $c$ there is no difference of elasticity, therefore no resultant motive force, and the particles $a$, $b$, and $c$ are all urged in a direction normal to the surface of the shell.

So far as concerns the general character of motion and the general configuration of the wave, there is no essential difference between an elastic wave in a gas and one in a liquid. But the elasticities of liquids are far greater in degree than those of gases To appreciate the difference it may be well to state distinctly what is understood by the term elasticity. It may, so far as concerns fluids, be defined as the resistance which the fluids offer to a change of volume by the

application of external forces. The elastic force of gases is a familiar phenomenon, but the elastic force of liquids is not often experienced in such a manner as to be similarly appreciated. But a liquid, for example water, is susceptible of compression by external pressure in precisely the same manner as air. The compressive force, however, which is required to effect a given reduction of volume is enormously greater in water than in air; being in fact (at 62° F.) nearly 22,000 times as great. But the density of water is about 773 times as great as air. Hence, if the law governing the rate of propagation be as already stated, the rate in water should be to that in air as 5.32 : 1, or as about $5\frac{1}{3}$ to 1. It is known by experiment to be a little more than four times as great. The discrepancy, however, is readily accounted for.

Here we may note the fact that two very distinct kinds of waves may occur in water: First, those visible waves of the surface which invoke the action of gravitation upon those portions of the water which are disturbed from the general level. Second, those waves which are produced by some impact or vibration of bodies immersed, causing a disturbance which calls forth the action of the elastic force inherent in the molecular constitution of the water. These latter waves differ in no essential respect from sound waves in air.

Waves in solid media involve considerations which are much more complex. They embrace all those which apply to waves in fluids and a group of additional ones quite as extensive and even more difficult and complex. It still remains true, however, that the motions set up by waves in solid bodies are those which involve only two related forces; the elasticity of the medium and its inertia. In the case of gases, we conceive of elasticity as that innate force by virtue of which the gas tends to expand either indefinitely or to some volume and density at which the internal elastic force is in equilibrium with the external forces acting upon it. In the case of liquids, we conceive of it as being that innate force by virtue of which the liquid resists being compressed by external forces into a volume smaller than some specific volume. But, as applied to solids, the notion of elasticity must be amplified by the addition of two distinct concepts which either do not exist or at least are not apparent in gases or liquids. Solid bodies resist elastically any external forces tending to compress them into a volume smaller than some specific volume; and thus far the conception of elasticity is common to both solids and liquids. But solids also resist any external force tending to expand them into a volume larger than some specific volume. We do not know that any such elasticity characterizes either liquids or gases, unless the cohesion known to exist in liquids may be regarded as manifesting it. Another highly important form of elasticity peculiar to solids is that force by which they resist a change of form independently of any change of volume. This kind of elasticity is wholly wanting in fluids; indeed, it is the absence of it which constitutes

the distinction between fluids and solids. They offer no resistances to free movements of molecules among themselves, except a peculiar form of resistance known as viscosity, which is devoid of the essential features of elasticity and is usually conceived of as a kind of friction among the molecules.

The elastic resistance which solids offer to expansive forces may be regarded as homologous with that which they offer to compression, and the only difference is in respect to direction. There remain, then, two distinct kinds of elasticity in solids, one of which is the resistance to a change of volume, the other to a change of form. The first is usually termed the elasticity of volume, the second elasticity of form.

That all solids possess elasticity of volume—that they are capable of being compressed into smaller volumes by external pressure—has never been directly proven by experiment. But no physicist seriously doubts that they are capable of such compression, though the force required to effect a sensible amount of it must be many times greater than that required to effect an equal compression in liquids; nor is it doubted that the resistance offered is truly elastic and of the same general nature as that offered by liquids and gases. It is elasticity of form that we are most familiar with. The steel spring, the vibrating reed, the billiard ball, and the bell are common examples of it.

If, then, solid bodies have two distinct kinds of elasticity, we may infer that they are capable of transmitting two kinds of waves, one depending on their elasticity of volume, the other upon their elasticity of form. We may conceive of a wave in a solid which may involve the action of elasticity of volume alone. For example, imagine an indefinitely extended elastic homogeneous solid and at some place within it a small spherical cavity filled with an explosive substance. Imagine this substance to be exploded in such a manner that the suddenly generated forces act radially outwards and with uniform intensity against every point of the surface of the cavity. The enveloping medium being compressed uniformly, an elastic wave would be generated differing in no essential respect from an elastic wave in water or in air. Its propagation and the motions or vibrations of its constituent particles would be essentially the same. We may also conceive of a wave in a solid which may involve the action of its elasticity of form alone. A bar of steel subjected suddenly to a stress of pure torsion is a case in point. Or, again, conceive of a circular saw with its teeth held against some obstacle which prevents its rotation. Imagine a sudden rotary force applied to the axle. It would generate a wave of distortion in the disk of the saw, which would propagate itself in expanding circles to the periphery. In the twisted bar and in the saw no change of volume would take place, but only a change in the configuration of

the component molecules of the metal. This change of configuration among the particles is resisted elastically by two forces: First, the inertia of the particles; second, by the innate forces of the particles, which (in solids alone) tend to hold the particles in their positions relatively to each other. The disturbance is propagated from layer to layer away from its origin in a manner analogous in many respects to that of a wave of compression. But there are other respects in which the two kinds of waves differ. In the wave of compression the direction of vibratory movement of the particles is to and from the origin of the wave and coincident with the direction of wave propagation. In the wave of distortion the motion of the vibrating particles is transverse to the direction of propagation. The wave of compression is usually termed the normal wave, because the direction of vibration in the particle is normal to the surface of the spherical shell which at any instant contains the wave. The wave of distortion is usually termed the transverse wave, because the motion of the particle is transverse to the radius of the spherical shell or to the direction of the line of propagation.

The cases which have been suggested of pure normal waves (of compression) in solids on the one hand and of pure transverse waves (of distortion) on the other are rather ideal than real. The incident forces or impacts to which solid bodies are subject in the real occurrences of nature are usually such as initiate both compressions and distortions, and generate at once both normal and transverse vibrations in the particles of the medium. A few special cases may be suggested in which certain bodies of definite forms might in reality be subjected to forces producing distortion without any sensible amount of compression and thus generate pure transverse waves. The torsion of a rod of metal approximates to the conditions necessary for a pure transverse wave. But it is difficult and perhaps impossible to conceive of any real source of pure normal waves. We are required, therefore, to consider waves in solids under the twofold aspect of normal and transverse vibration. Here the difficulty of conception greatly increases.

It may aid us in the endeavor to grasp this complex idea if we recur to the familiar motions of water upon the surface of the ocean. Here we observe a commingling of many undulations of widely varying wave lengths and amplitudes, and though there is a predominant direction of propagation there is also much divergence of direction. The speed of propagation also varies, being greater in the large waves and less in the small ones. Howsoever the motions due to different waves may combine—here one or more undulations uniting for an instant into a single one, there interfering and for a moment destroying each other's motion—every wave preserves its individuality. This is never lost; though for a moment, as two waves occupy the same space, it may vanish from the vision of the spectator,

it quickly reappears, and each wave separates itself unimpaired and as distinct as before. The double wave set up in elastic solids by natural forces of impact or otherwise may consist at the initial moment of a single vibration of each affected particle, the direction of vibration being compounded of a normal motion and a transverse one. This arises from the fact that the rate of propagation of normal vibrations differs from that of transverse ones in the same solid medium.

We have seen that the rate of propagation of an impulse depends upon the inertia of the particles (or what is equivalent, the density of the medium) and the elasticity. But elasticity may be measured by the amount of force required to effect a given displacement of particles relatively to each other. There are two kinds of displacement to be considered ; one involving a change in the mean value of the intervals between particles irrespective of any change in their relative configuration ; the other involving a change of configuration without change in the mean value of the intervals. With equal displacement, the force required to effect the first kind is greater than that required to effect the second. That is to say, the elasticity of volume of a solid exceeds its elasticity of form. Since the speed of propagation of a normal wave must depend upon its elasticity of volume and the speed of a transverse wave upon the elasticity of form, it follows that the former will be propagated more rapidly than the latter. Thus the wave of transverse vibration must lag behind the wave of normal vibration, and the two motions, though they may in the beginning have been combined, must immediately separate.

We may further aid our conceptions by another illustration. Taking again the imaginary case of a spherical cavity within a homogeneous solid, suppose a rapid succession of explosions to occur, each generating a pure normal wave. After a time imagine some arbitrary force applied to the surface of the cavity in such a manner as would tend to produce a rotation of the hollow sphere around any axis. Let this force be applied and withdrawn repeatedly in rapid succession. Pure transverse waves would be generated which would be superposed upon the normal ones, and they would be propagated independently of the latter. Their distinctness and individuality would be preserved as certainly as those of water waves, and they would be propagated at their own rate, depending upon the elasticity of form only, while the normal waves would travel with a speed dependent upon the higher elasticity of volume. All natural or real impacts upon solid bodies evoking elastic resistance involve both compression and distortion, and though the compound action must generate a compound wave of compression and distortion at the first instant, the separation of the two elements is inevitable.

The speed of wave propagation in solids is in general much greater than in liquids. This is because the ratio of elasticity to density is generally, if not always, much greater. So great is the

volume elasticity of solids, that it is extremely difficult to measure. In fact, it never has been measured directly in any solid. But we have a theoretical law governing the relation between elasticity of volume and elasticity of form, and approximate measurements of the latter have been made, so that knowing by experiment the value of the one the other can be computed from it.

The propagation of a normal wave in an indefinitely extended mass of steel has never been directly measured. In a steel bar it has been ascertained to be nearly 17,000 feet per second; from which the computed speed in an indefinitely extended mass is about 21,000 feet per second.[1] We could also compute the rate in any other substance

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[1] The speed of a transverse wave is proportional to the square root of the elasticity of form only and is independent of elasticity of volume; but the speed of the normal wave depends upon both. For if BADE be a portion of the spherical shell of a normal wave, in which D*fe*E is the amount of compression, it will be seen that the matter contained in BA*fe* has been subject not only to change of volume, but also to change of form. It resists the compression therefore by virtue of both elasticities. If K be the elasticity of volume and $n$ that of form, it can be proven that the elastic resistance will be proportional to $(K + \frac{4}{3} n)$. The above case supposes the wave to traverse a solid extending indefinitely in all directions. Take the case of a long square bar of steel. Let BADE be

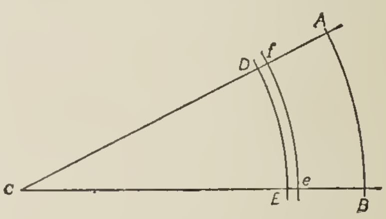


Fig. 40.

a portion whose length bears a small ratio to the wave length. When the wave is passing it a compression takes place in such manner that DE is forced nearer to AB or to *de*. But the four sides of the parallelopipedon are also bulged out. Here, too, both elasticities are called into action. But the conditions differ from those of the first case. In the indefinite solid no lateral bulging can occur, because the metal surrounding the mass laterally is equally strained and equilibrates the lateral bulging tendency. It can be proven that in the steel bar the total elastic resistance is $\frac{9\,K\,n}{3\,K + n}$. This is the expression for what is termed "Young's modulus." It is the quantity usually ascertained by subjecting specimens of metal to a longitudinal pull or thrust in a testing machine. It does not, however, give us either of the elasticities alone. To ascertain them it is necessary to find one by some process which calls into action that particular elasticity and not the other. No practicable way has ever been devised for satisfactorily measuring pure elasticity of volume. But elasticity of form can be measured. The usual way is by subjecting cylindric rods or wires to torsion and measuring the force required to produce a certain amount of it. Torsion appears to involve no change of volume, at least in small amounts of twist. The difficulties, however, are considerable. Having found the elasticity of form, we may substitute its value in Young's modulus and derive the elasticity of volume. The proofs of these statements may be found in Thomson and Tait's Natural Philosophy, and a summary is given by Sir W. Thomson in the Encyclopedia Britannica, article Elasticity. The same result is differently reached by Lamé in his beautiful and profound work Theorie de l'Élasticité. Thomson's proof is suited only to advanced scholars. It has, however, been amplified and simplified by Balfour Stewart and Gee, and made more intelligible to those versed in the elements of mathematics and physics in their excellent little book, Lessons in Elementary Practical Physics. Macmillan & Co. 1885.

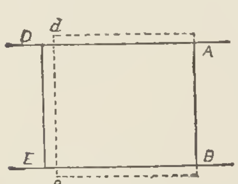


Fig. 41.

if we knew its two elasticities and its density. Thus the elasticities of various kinds of glass have been measured; also of iron, copper, and brass, from which the wave speeds can be roughly computed. In the case of glass, the speed of a normal wave in an indefinitely extended mass is computed to range between 16,500 and 17,500 feet per second; and in hard copper to be about 16,500 feet, and in brass about 15,000 feet per second.

Hitherto the discussion has implied that the medium which transmits waves is homogeneous. It is now necessary to examine the meaning of the word "homogeneous," in order to see how much it implies and what qualifications of its meaning have to be considered. Its usual meaning is a perfect likeness of all the parts of a body in respect to physical properties when the smallest parts considered are of sensible size.

If matter be composed of discrete molecules and atoms, and if we were to consider parts so small that they embraced only a small number of molecules, no body could be regarded as homogeneous, for the molecules would be unlike the interstitial spaces around them.

Rigorously speaking, homogeneous bodies do not occur in nature, though some substances, especially liquids, may be regarded as being so nearly so, that no material error would be involved in considering them perfectly homogeneous. Most solids are far from homogeneous, but a considerable number, especially crystals, approach that condition. There are, however, some considerations connected with crystalline bodies and some others which are of importance, and which lead to some qualification of the idea of homogeneity. When crystals are subjected to any incident forces the result depends upon the direction with respect to the principal axes in which the forces are applied. Passing over their behavior with respect to heat, their cleavage, and their optical properties, we know that their elasticities differ in different directions relatively to their axes. But this does not imply any defect of homogeneity, for these qualities are shared equally by all parts of the crystal. They are special properties which may and do coexist with homogeneity, and special account must be taken of them. They are all comprehended in the general word "polarity." A homogeneous body whose elasticity is equal in all directions is said to be "isotropic;" when it is different in different directions, it is said to be "eolotropic" or heterotropic. The property of eolotropy is supposed to be the result of the arrangement of the molecules. It is not confined to crystals. Metals sometimes possess it, presumably in consequence of the forces to which they are subject in the process of manufacture. Thus the elasticity of an iron bar is presumably not the same in the direction of its length as in the direction of its diameter. It may even have different elasticities along different diameters, and instead of having one elasticity of volume may have two or three. So, too, it may have more than one elasticity of

form. Since, then, the rate of propagation, the consequent form of the waves, and the motions of the particles must depend upon the elasticity, we begin to realize how complex the subject must become when we take account, as we must, of the manifold elasticities of bodies. It can be handled only by the wonderful machinery of mathematics.

An earthquake consists of a series of many elastic waves passing through the substance of the earth. The nature of the action which generates such waves is still an unsolved problem. But for their progress and motions after they are once generated we have a theory which is satisfactory so far as its general features are concerned. The preceding discussion is an attempt to express in common language the fundamental principles upon which that theory is based. In applying it to earthquakes, we must take account of several facts which must modify to an important degree the conclusions to be drawn from it.

(1) The earth-mass through which these waves are transmitted is not homogeneous. Both the elasticity and the density of its matter vary. Near the surface of the earth the variations are very great. The superficial covering consists mostly of soil of varying degrees of compactness, comprising silicious particles of widely varying degrees of coarseness or fineness without any solid cementing material uniting them into a continuous mass like the indurated strata. Moreover, the harder and more compact rock-masses near the surface are riven with myriads of cracks breaking their continuity at short intervals. Every crack causes a corresponding break in the continuity of the physical law governing the propagation of the waves. If we consider a layer of sand or soil as consisting of small silicious grains touching each other only at a few points and with interstices filled only with air or water, we shall perceive that its elasticity must be of a very much lower order than that of a consolidated mass of similar grains whose interstices are filled with a cementing material as hard and elastic as that of the grains themselves. But even such loose materials are not wholly devoid of elasticity, as is sufficiently proven by the fact that they transmit wavelets or tremors as truly as more homogeneous masses, though not so swiftly or perfectly. So also in rocks which are fissured or cracked. The wave impulse is quickly lost, not only because it is diffused through an ever-expanding shell, but also because a part of its total energy is extinguished at each break of continuity or dispersed by reflection, like a water wave breaking against a rough, irregular barrier, or waves of light falling upon a rough surface. There is, however, reason to believe that in the depths of the earth the rock material is continuous. Cavities, interstices, and cracks cannot exist at great depths. The weight of superincumbent masses is sufficient a few miles below the surface to render everything perfectly

continuous even though everything may not be strictly homogeneous.[1] It is in these depths that the principal part of the energy of the earthquake wave is propagated. The modifications which those portions of the spherical wave which move more or less obliquely upward receive as they pass from the more solid masses below into the less compact strata above will be discussed farther on.

(2) Another condition which modifies the movement of the earthquake wave is imperfect elasticity of the medium through which it is propagated. Perfect elasticity is conceived of as the property by which each particle of the mass returns to its original position after the wave impulse, and suffers no permanent change either of volume or of form. So far as concerns the volume of truly homogeneous and continuous solids the elasticity is probably perfect. Not so with elasticity of form. Even in those solids in which the resilience seems to be perfect—as in a steel spring—it is not so. In every vibration of the spring there is some permanent change of the relative positions of particles and it is greater in substances whose resilience is less perfect. Every such change involves a change of a portion of the wave's energy into heat or some other mode of motion. The portion of energy so transformed is not transmitted. The proportion of energy thus lost by the wave increases with the amplitude of vibration. It is a familiar fact that whenever a solid is subjected to stress exceeding a certain amount it undergoes a permanent deformation, which increases so long as the stress remains or until ended by rupture. We can easily conceive of a solid subjected to a wave-producing impulse powerful enough to surpass the "elastic limit" of its material, as when an iron target is struck by a cannon-shot or as when dynamite is exploded in rock-blasting. In such cases much the greater part of the impulse is transformed into work done upon the material and only a small part remains to be transmitted. The intensity of the transmissible energy can not exceed a certain amount, depending upon the elastic limit of the substance. The effect, then, of imperfect elasticity is to dissipate more or less rapidly the energy of the wave. Since the intensity of the energy (amount of energy per unit area of the spherical shell surface or per unit volume of the shell) must diminish as the inverse square of the distance even when the elasticity is perfect, it is apparent that it must diminish in a still higher ratio when the elasticity is imperfect.

(3) The third consideration arises when we pass from the idea of a solid medium extended indefinitely in all directions to that of a medium limited on one side at least by a plane surface. This consideration applies to earthquake waves which originate within the mass

[1] Those who speculate upon the existence of deeply seated cavities within the earth overlook the unavoidable and indisputable conclusion from the law of gravitation that at a depth of four or five miles the pressure of superincumbent masses exceeds the rigidity of the strongest rock-forming material.

of the medium and are propagated in such a manner that nearly one-half of the spherical shell ultimately makes itself felt at the surface of the earth. In a homogeneous and perfectly elastic solid the existence of a bounding surface would have no effect upon the wave until it reached very near the surface—nearer in fact than one-fourth of a wave-length. The most forcible shocks of a great earthquake, however, have very considerable wave-lengths. Some of them may have wave-lengths of nearly or even quite a mile, with an amplitude varying from a fraction of an inch to several inches. In such waves the effect of the surface in modifying the motions of the particles would be decidedly appreciable. If we remember that during the forward half of a vibration the medium is subject to compression or squeezing, we shall be able to realize that at the surface the medium is free to bulge upwards. But it is restrained from bulging laterally, or horizontally, because the matter which is horizontally adjacent to any elementary portions is subjected to the same tendency to bulge laterally. Hence over the half of the wave which is subject to forward motion a surface bulging occurs, while over the part of the wave which is subject to refluent motion a depression would be formed, thus giving rise to an undulation of the surface resembling (but not homolgous to) the long waves on the surface of a body of water. But their amplitudes in vertical dimension would be very small—smaller even than the amplitudes of the elastic normal waves which produce them—while their wave lengths would be very great. Such slight deformations, therefore, would be quite invisible. But they would undoubtedly be felt very keenly by the general sense of feeling, for we are very sensitive to minute displacements of the ground or floor on which we stand when they take place quickly; and the earthquake wave moves with immense rapidity. It is clear, however, that these cannot be those visible surface waves which are so often testified to as occurring in great earthquakes in and near the epicentral tracts, for the latter are, according to all accounts, of considerable amplitude and of comparatively short wave-length.

A far more important consequence of the bounding surface of the solid is that it causes a reflection of the wave. If upon the other side of the surface there is another medium of different elasticity or density, a part of the wave will be transmitted into it and a part will be reflected back into the original solid. If there is no such medium, the whole wave will be reflected. An elastic wave from within the earth rising into a body of water is almost totally reflected back from the surface downward through the water again. A small part of its energy, however, is transmitted to the air, becoming a wave of sound which is distinctly audible. If the surface of the water is disturbed by common gravity waves, the elastic wave is broken up into a great number of minor waves, and many fractional waves are transmitted to the air, becoming a confused murmur of sounds.

Passing from the idea of a solid homogeneous throughout to one which, like the earth, is covered with a superficial layer of loosely aggregated material, we may next consider the modifications of the waves produced by such changes in the character of the medium as actually occur. As already stated, we must regard the moderately deep rocks as thoroughly compact and continuous; and as we have some reason to believe that they do not differ greatly in constitution (at least until profound depths are reached), we regard them as approximating homogeneity. But the superficial strata are quite otherwise. As an earthquake wave approaches the surface it passes through a succession of layers which not only differ widely in respect to elasticity, but are interrupted by cracks or joints, while the soil is composed of a material radically different in respect to elasticity from the consolidated strata. Thus the wave is greatly modified. Wherever the character of the rocks changes suddenly a part of the wave is reflected and a part transmitted. And this is true both of normal and transverse waves.

We may thus realize that in the heterogeneous outer covering of the earth-mass the earthquake waves undergo a great amount of modification, being broken up into duplicated and reduplicated waves at every sudden break in the homogeneity, tending to become a confused series of divided tremors, at one place reflected, at another refracted. In passing from one medium to another the amplitude, wave-length, and speed of propagation change; either one or more of these component quantities increasing or diminishing (but conditioned by the law of the conservation of energy) according to the variations in the elasticity and density.

The shaking which is felt at the surface of the ground during an earthquake, therefore, is produced by waves which have been greatly modified in their passage through the upper layers of the earth. They do not give us the means of judging the exact character and dimensions of the deeper waves which have produced them ; much less do they furnish us with any clew as to the nature of the disturbance which originates the deeper waves in the first instance. But as the surface movements are dependent upon the subterranean ones, and as the nature of this dependence is in part at least, and even in great part, within the domain of legitimate theory, we find the examination of them not without utility. We may proceed, then, to discuss the broader features of the motions of the surface as actually observed.

The ingenious investigations which have been made in Japan by the native and European scientific men residing in that country have thrown much light upon this subject. The elaborate seismograph used by them records the movement of the ground in such a manner that it can be resolved into its proper components. This instrument has been so often described, that a description of it here

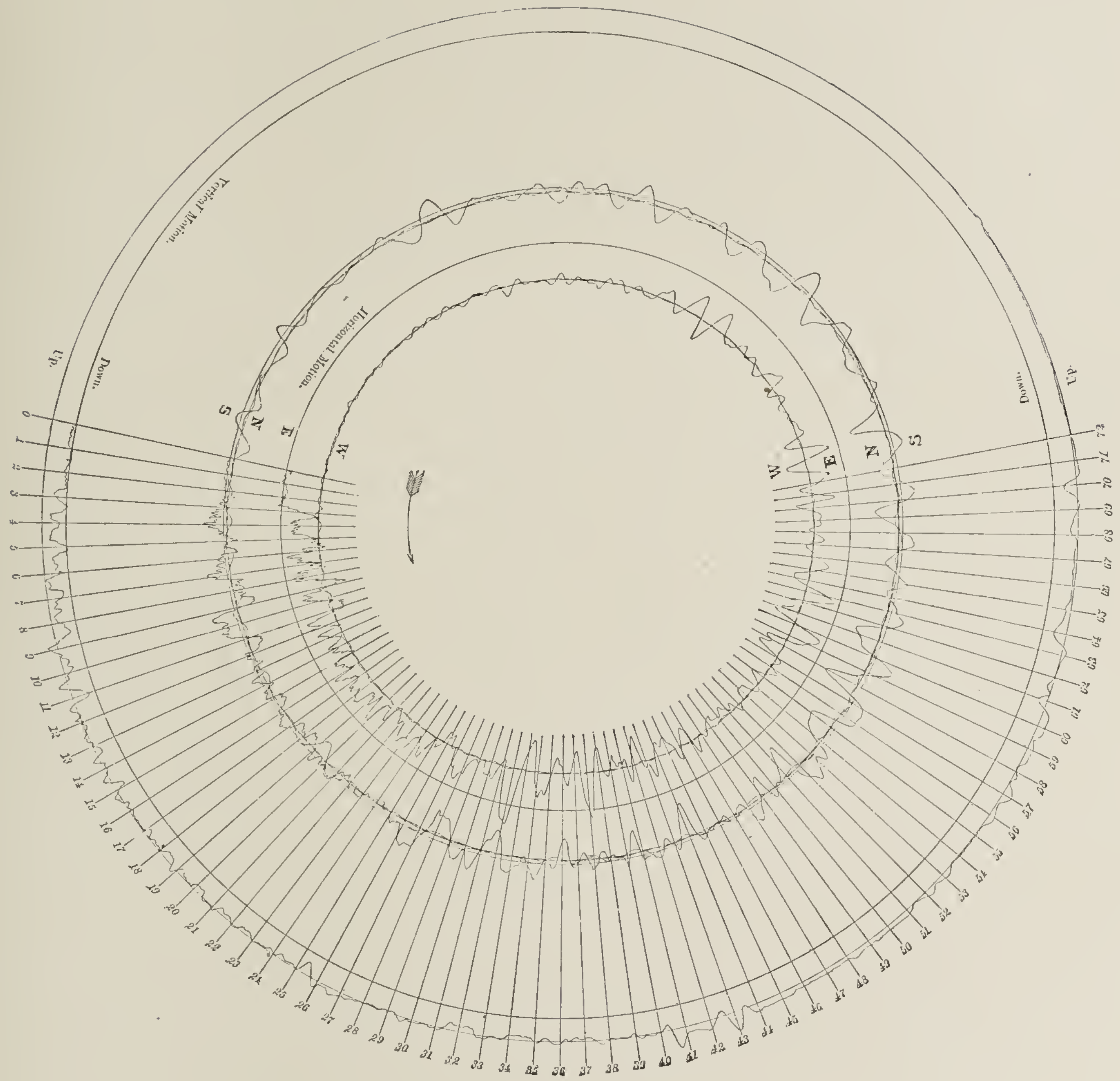
seems to be a useless repetition. Some recent investigations made by Prof. Sekei Sekiya[1] are of special interest.

The diagram in Pl. XXX shows the traces made by the instrument upon the revolving plate, in which the amplitudes of the horizontal vibrations are magnified five times and the vertical ones eight times. These give the three rectangular components of the motion at each instant of time during the whole disturbance. These being obtained, it becomes possible to reconstruct a representation of the path described by a point on the ground. This Professor Sekiya has done by bending a long wire into such shape that it shall represent that path. Pl. XXXI is a picture of the wire so bent. The first figure represents the motion from the first to the twentieth second; the second from the twentieth to the fortieth second; the third from the fortieth to the seventy-second second, at which time the vertical vibration became almost inappreciable, though the horizontal vibrations continued considerably longer. These confused tangles viewed by themselves indicate motions of the most irregular kind. But if we recur to the diagram of the circular plate the traces clearly indicate something more. They show that the tremors were many and that smaller ones were superposed upon larger ones; that the larger ones had periods varying somewhat, but not differing greatly from two seconds. The greatest amount of vertical movement was only 1.3 millimeters, or about one twentieth of an inch; while the greatest horizontal displacement was 7.3 millimeters, or between one-third and one-fourth of an inch. The smaller tremors at the beginning of the earthquake were five or six per second, but after twelve or fifteen seconds they vanished, while the principal vibrations continued as a series of long and nearly regular oscillations, dying out very gradually after the eighty-fifth second. This earthquake occurred on the 15th of January, 1887, and was of somewhat unusual severity. At the point where the above observations were made the intensity of the shocks, as nearly as I can estimate from Professor Sekiya's description, was about equal to that of the Charleston earthquake at Atlanta, Ga.

The foregoing example may be regarded as a fair type of the movements of a particle upon the surface of the ground during an earthquake. The amount of motion in different earthquakes may differ greatly. In the greater ones the amplitudes are much greater, but the general nature of the motion is the same. This motion is the resultant of innumerable waves, some normal, others transverse, with two or more superposed vibrations passing at the same instant.

In attempting to reason from such movements at the surface to those in the depths we encounter great difficulties and uncertainties. We have seen that the primitive waves in passing from a nearly homogeneous medium below into different media above are decom-

[1] Transactions of the Seismological Society of Japan, vol. 11, 1887, Yokohama.




SEISMOGRAPH TRACES.

posed, so to speak, and modified greatly in respect to their amplitudes and total energy, and new waves differing from the primitive ones are generated. We can not reconstruct primitive waves out of the data furnished by the secondary ones. All that we can do is to state, according to theory, the general nature of some of the transformations.

The materials which compose the soil, the gravels, and the unconsolidated uppermost strata have elasticity, but its degree (or modulus) is very much less than that of the rocky strata, while their density is only a little less. As these two properties govern the rate of transmission, it is obvious that the wave-speed in such materials must be less. But the amplitude of the motion must be greater at the surface; for, the elastic resistance being less, a given impulse will project the particles to a greater distance before the elastic resistance becomes great enough to stop their motion and drive them back to their original positions. The wave-period, or time of oscillation, on the other hand, will be increased. Where a rapid and long-continued succession of waves passes, there will be a tendency of the lower material to assume a series of increasing oscillations, whose component quantities, wave-length, amplitude, and period will be dependent, first, upon the average values of those quantities in the primitive waves; second, upon the peculiar properties of the mass; third, upon the surface conditions; and fourth, upon the obliquity of the rays of the emergent waves. These are so complex, that no discussion of the nature here contemplated can throw light upon them. That gravity waves strictly homologous to those we see in water may be among the resulting motions is quite possible from a theoretical point of view, though the explanation of them is attended with difficulty.

We may now proceed to consider how the motions produced in the epicentral tract and its vicinity may differ from those produced at greater distances. Taking first the normal waves, in which the direction of motion of the vibrating particles is the same as the radius of the wave-shell, it is apparent that at the epicentrum the motion of a particle in a pure normal wave must be up and down, or, as it is usually termed, subsultory. As we pass away from the epicentrum this motion becomes more and more oblique, and at a great distance it becomes sensibly horizontal, but in a direction to and from the centrum. In the case of transverse waves the motion produced at the epicentrum is horizontal. But it may have any azimuth, i. e., any direction in a horizontal plane. Any single wave, however, due to some definite impulse must have some definite azimuth of vibration at each point affected by it, and this will be determined by the special character of the original impulse. Away from the epicentrum the transverse vibration may have any direction in a plane perpendicular to the line joining the point of observation and the centrum. This plane is always an oblique one with respect to

the horizon, and the vibratory motion can be strictly horizontal only when the direction of vibration coincides with the intersection of the oblique planes with the plane of the earth's surface. Hence the most forcible vertical vibrations must occur at the epicentrum, and these must be due to the normal waves alone; for at the epicentrum the transverse waves yield no vertical motion at all, and at great distances from it both waves become enfeebled by steadily diminishing amplitude. In the epicentral tract, therefore, we may not be surprised to find evidence of forcible subsultory movement, while away from it we find little or none. In the Charleston earthquake the effects of the vertical shocks in the epicentral tract were disastrous and gave wholly different aspects to the vestiges of the catastrophe from those disclosed in Charleston.

Since many simultaneous waves may be passing at the same time and place, the resulting motions given to the earth particle may be highly complex. But at or near the epicentrum there may be peculiar compound motions, which are either not manifested at a distance or are so little pronounced as to be hardly noticeable. As already stated, the motions due to a pure transverse wave at the epicentrum must be horizontal vibrations, and for any single wave they can only have one azimuth. The vibration will then be in a straight line. But suppose another transverse wave causing vibration in a different azimuth acts upon the earth particle at the same time. The result will be in general that the earth particle will describe a closed circuit, the form of which may be almost indefinitely varied. Where the amplitudes of the transverse waves are very great and the relations between the phases of the conspiring waves conform to certain conditions, the path of the earth particle may become nearly circular, producing those remarkable motions known as "vorticose." Movements somewhat similar may indeed be produced at more distant places by combined vibrations, but it is only when the amplitudes are great and the shaking correspondingly energetic that they are of sufficient magnitude to distinctly impress their real character upon the senses of the observer.

An estimation of the energy of an earthquake involves the consideration of numerous component quantities and their relations to each other. In general it may be said that the energy depends firstly upon the extent of the motion, and secondly upon the quickness with which it is performed. But we need to make our conceptions and understanding of these general terms more specific. To this end it is necessary to consider the elementary quantities which constitute vibratory or undulatory motion, and see how they are related to each other and how they make up collectively the energy of the earthquake. The quantities to be so considered are the amplitude of motion, the wave-length, the period, the wave-speed, and the acceleration of the earth particle.

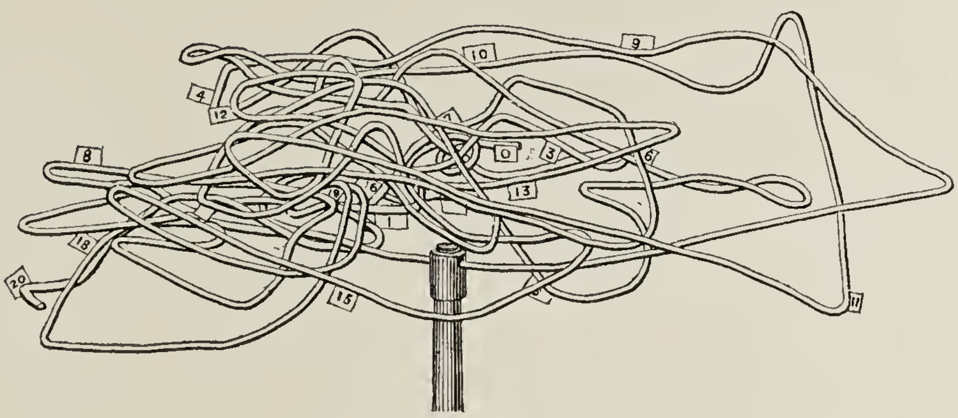



*Fig. 1.*

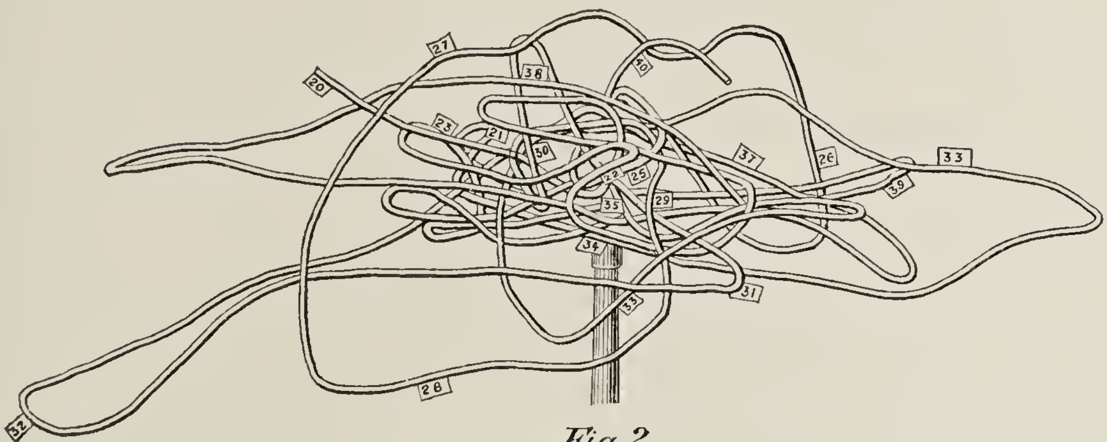



*Fig. 2.*

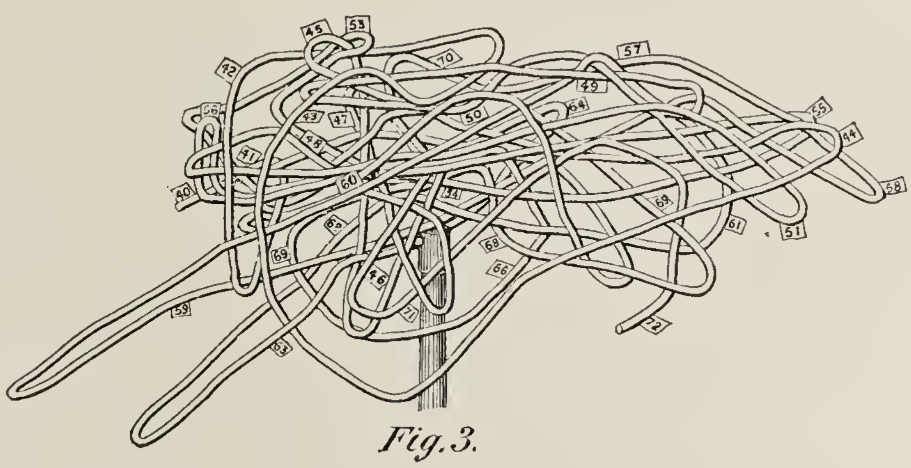



*Fig. 3.*

SEKIYA'S WIRES.

(1) The amplitude has already been stated to be the length of the path through which a given particle vibrates under the impulse of a single wave. In this case its path is a straight line, whether the wave be normal or transverse. But under the action of two or more simultaneous waves its path may be a closed circuit, and under a long succession of impulses, some superposed, others following in harmonic series, its path becomes extremely complex, as exemplified in Professor Sekiya's model in wire. In so far as we can identify any compound vibration, the amplitude may be regarded as the extreme distance of its excursion from the mean position, or rather from that position in which it would be in equilibrium if all impressed forces were suddenly to cease. This quantity has been measured many times in Japan by the seismographs, and though such measurements probably do not attain a high degree of accuracy, they are near enough to the truth for practical purposes. They indicate an amplitude much smaller than was supposed to characterize similar and equal shocks before such instruments were used.

(2) The next important quantity to be considered is the wave-period, or the time required for a complete oscillation. In a perfectly elastic body the wave-period depends wholly upon the nature of the originating impulse. When a force like a push or an impact is applied to a solid elastic mass, it causes both compression and distortion. So long as this force exceeds the elastic resistance, the compression and distortion will continue to increase. But the increase of distortion or compression is accompanied by a proportional increase of the elastic resistance, and when this resistance becomes equal to the force applied, the change of volume or figure ceases. A diminution of the applied force is then followed by a return of the displaced portions towards the original configuration. Now the disturbing force may be applied slowly or it may be applied quickly, but so long as it continues to be greater than the elastic resistance, so long will the displacement continue to increase. Since the speed of propagation is constant, the longer the time in which the force exceeds the resistance the greater will be the wave-length; the greater also will be the wave-period, for the period is the time required for a wave moving with uniform speed to pass a given point. We may, then, use the terms wave-length and wave-period as correlatives, the first expressing the space relations, the second expressing the time relations of the same fact. Recalling the statement that the vigor of an earthquake impulse depends upon the extent of motion and the quickness with which it is performed, we may substitute more technical though hardly more precise language, and say that it depends upon the amplitude and period.

The seismograph gives us a measure of the wave-periods as well as of the amplitudes. In those observed in Japan they are found to vary from one-tenth of a second to over two seconds. It may be

questioned whether still smaller periods do not occur, but which fail to be recorded owing to the size and form (moments of inertia) of the moving parts which trace the records on the revolving plate. It is a striking fact, brought to light by these instruments, that in the beginning of a forcible earthquake, tremors of a very short period appear superposed on waves of longer period ; but after the lapse of a few seconds they disappear or become far less conspicuous, and the ground settles into a comparatively slow swing, the pulses being from half a second to two and a half seconds in duration.

(3) Of the speed of propagation nothing needs to be said here, a whole chapter being devoted elsewhere to the discussion of this factor.

(4) The wave-length has also been discussed as to its main features. It may be added that it is obviously equal to the speed of propagation multiplied by the period. It is necessary to bear in mind, however, that we have as yet no assurance that the wave lengths, speeds, and periods of the surface vibrations correspond to those which belong to the deeply seated waves in the earth which bear along the chief part of the total energy of the earthquake. We have seen that there must be an enormous difference in the elasticities of surface and deeply seated materials respectively, while the densities differ not greatly. Hence the speed must be less and the wave-length for equal period correspondingly so. Still more generally we have regarded the surface waves as different waves from those beneath, though produced by them. A knowledge of the speed of the deep wave, therefore, conveys no knowledge of the speed of the secondary surface wave. We are then in the following difficulty: We have three quantities ; speed, period, and wave-length. The seismograph gives us the period, and we know that the wave-length is the product of the other two quantities. To assign values to them all we must have a third datum or relation. But no such datum or relation, so far as I am aware, has ever been determined in any earthquake for surface waves. Nor have we the means for assigning any definite relations between the quantities pertaining to the deep waves on the one hand and to the surface waves on the other. There seems, however, to be good reason for presuming that the short, quick tremors which usher in the earthquake have periods not greatly differing from those of deeply seated vibrations; periods which may range from one-tenth to one-fifth of a second. If these may be assumed to represent also the periods in the Charleston earthquake, the deep wave-lengths would range from 1,700 to 3,400 feet. It is not disputed, however, that some of the longer periods disclosed by the seismograph may agree with those of deep waves, in which case their lengths would vary from one and a half to eight miles. Putting such figures into relation with the possible amplitudes, which in the most violent shocks can hardly exceed a few inches, we gain

some idea of the enormous disparity between amplitude and wave-length. Remembering that the amplitude decreases as the wave moves on, and that at the distance of a few hundred miles it can not exceed a very small fraction of an inch, while the length of the wave remains constant, the disparity is greatly multiplied. But it is not impossible. Nay, some enormous disparity is certain. It is only a question of how much, and that which has been roughly suggested is intrinsically as probable as any others. The ratio of amplitude to wave-length in the surface waves is probably many times greater, the amplitude being much greater and the wave-length very much less.

(5) The "acceleration of the earth particle" is a term used to express the amount of force actually exerted by the wave upon a body situated upon the earth's surface. If a body is free to move, the application of force will cause motion or change of motion. In this connection a state of rest is considered as the zero of motion. A change of motion is called an acceleration. It requires a force in order to produce it, and the amount of the acceleration is simply proportional to the force which causes it.

The final quantity to be considered is the energy per unit area of wave front. This is the true measure of the intensity, as that word is accepted and understood in this paper. It is a complex idea, being dependent upon four factors: the wave-length, the amplitude, the wave-period, and the density of the medium. We might substitute for wave-length an expression for the wave-speed, but the quantity would not be simplified thereby. Conceive a square segment whose area is unity to be cut out of the spherical shell which contains the advancing wave at any moment. The total energy of the segment is the sum of the energies of its constituent particles. But the energies of different particles at any instant are not uniform. Those on the outer surface of the shell are just beginning their motion; those on the inner surface are just ending it. Those between the two surfaces are in different phases of their motion, according to their distances from either the inner or outer surface.

It may be questioned by some whether the energy per unit area of wave front or the acceleration of the earth particle is the better measure of the relative intensities of seismic waves. To me it seems unquestionable that the former is to be preferred.

## APPENDIX A.

### LIST OF LOCALITIES FURNISHING REPORTS.

The following list embraces those localities which have furnished reports of some value. The mere indication that a shock was felt is of no significance except in the most distant regions. Wherever a marked intensity prevailed it is presumed that the tremors were universally sensible throughout the immediately surrounding region, and a few good observations well scattered will give as good indications for that region as could be expected under the circumstances. Within the isoseismal lines of three or four, mere indications that it was felt, and which give no further information, have been as a general rule excluded from the list. The time observations have been carefully sifted and catalogued in Chapter VII.

The latitudes and longitudes of the table have been somewhat roughly computed, being taken by scale measurements from the Atlas of Rand, McNally & Co. They are probably within two or three minutes of the true latitudes and longitudes in nearly all cases.

*Report of earthquake observations, earthquake of August 31, 1886.*

## ALABAMA.

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. (m.) | Duration. (s.) | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | m. | s. | | |
| 1 | Auburn | Lee | 32 36 | 85 23 | | | | 30 or 40 | Associated Press | Large brick building trembled violently; rumbling at first; windows rattled. |
| | ...do | ...do | 32 36 | 85 28 | | | | 30 | P. H. Mell | Sleepers generally awakened. |
| 2 | Birmingham | Jefferson | 33 30 | 86 46 | | | | | Dr. William Gesner | Table and windows shook violently and rattled; strongest in upper stories. |
| | ...do | ...do | 33 30 | 86 46 | | | | | Augusta (Ga.) Chronicle. | Slight but distinct shock; guests came out of hotels. |
| 3 | Blouutsville | Blouut | 34 07 | 86 34 | 1 | | 3 or 4 | | F. B. Gulliver | Information from others in houses; he and others outside hardly noticed it. |
| 4 | Calera | Shelby | 33 07 | 86 44 | | | | | New Orleans L'Abielle, September 3, 1886. | |
| 5 | Camdeu | Wilcox | 31 59 | 87 16 | 1 | | | 5 to 10 | T. S. Caldwell, assistant postmaster. | In chair, first floor, 6 feet from ground; clay foundation; no noise; intensity moderate; chandeliers and suspended objects swung; oil in lamp swayed; doors and sashes rattled; horizontal and undulatory; chandeliers in church swung ENE. to WSW.; clock, pendulum 3¼ feet long, facing nearly SW., stopped. |
| 6 | Carrolltou | Piekens | 33 15 | 88 03 | | E. to W | | 2 | D. C. Hodo | Duration about 2 seconds. |
| 7 | Centre | Cherokee | 34 08 | 85 42 | | | | | T. Bradford | Bulletin Alabama weather service; great deal of commotion; houses rocked and the timbers creaked and strained. |
| 8 | Clanton | Chilton | 32 52 | 86 38 | | | | | J. S. Edwards | Water rose in wells; "the hot well," 52 feet deep, rose in 2 feet of its top; temperature remaining the same. |
| | ...do | ...do | 32 52 | 86 38 | 2 | WSW. to ENE. | | | S. A. Blaisingame | Noticed by everybody; ruined plastering; some wells went dry, others flowed freely. |
| 9 | Cullman | Cullman | 34 10 | 86 48 | 2 | | | 2 or 3 | Prof. P. Mohr | Facts obtained from others; no noise; undulatory. |
| | ...do | ...do | 34 10 | 86 48 | | E. to W | | | W. Richter | Windows rattled; house shook violently; oscillations; lamp on table thrown over; house wall cracked. |
| 10 | Decatur | Morgan | 34 36 | 86 58 | | SE. to NW | | 30 | A. C. Frey | No noise. |
| 11 | Florence | Lauderdale | 34 48 | 87 40 | 3 | | | | J. W. Milner | Alabama weather service; distinct undulations, intervals a few secouds; windows and furniture shook. |
| 12 | Gadsden | Etowah | 34 02 | 85 57 | | | | | F. B. Gulliver | People ran from houses. |
| 13 | Good Water | Coosa | 33 04 | 86 04 | | | | | G. E. Weber | |
| 14 | Greensborough | Hale | 32 41 | 87 34 | | | | | Montgomery Daily Dispatch, September 1, 1886. | Considerable excitement; lasted several seconds. |
| 15 | Mobile | Mobile | 30 40 | 88 03 | 1 | SW. to NE | | 2 | Associated Press | Very slight; from SW.; felt in top floors; chandeliers swung; undulatory. |

*Report of earthquake observations, earthquake of August 31, 1886*—Continued.

**ALABAMA—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | | | | |
| 16 | Montgomery | Montgomery | 32 23 | 86 17 | | E. to W | | 30 | Associated Press | Perceptibly felt; largest buildings swayed, inmates left upper stories; not felt on ground floor; no noise. |
| | do | do | 32 23 | 86 17 | | | | | Montgomery Daily Dispatch, September 1, 1886. | Undulatory; duration "very short," variously estimated from four seconds to two minutes; much excitement; buildings rocked and quivered; lamp-shades, doors, and windows rattled; oil in bowls agitated; timbers creaked; some rushed to the street; prisoners greatly frightened; a few made dizzy; party sitting facing S. swayed E. and W. |
| 17 | Opelika | Lee | 32 37 | 85 22 | | | | 15 to 30 | G. E. Weber | Accompanied by rumbling; frame building, brick supports, swaying and vibrating; in one house pictures thrown down, another plastering cracked; duration thirty seconds, with interval of ten seconds. |
| | do | do | 32 37 | 85 22 | | | | | Atlanta Constitution, September 2, 1886. | |
| 18 | Oswichee | Russell | 32 10 | 85 00 | 3 | | | | W. C. Whitaker | Alabama weather service; very decided shock; two slight shocks at intervals of a few minutes; buildings vibrated considerably. |
| 19 | Oxford | Calhoun | 33 36 | 85 50 | 2 | NE. to SW | | | Atlanta Constitution, September 2, 1886. | First shock of fifteen seconds' duration; houses rocked lengthwise; undulatory; second tremor slight and lasted several minutes. |
| 20 | Ozark | Dale | 31 27 | 85 36 | 1 | | | 3 to 5 | E. W. Griffith, postmaster. | First floor, frame house, on sand hill, sand very deep; no noise; some felt three shocks; light one ten minutes earlier and moderate one seven minutes later. |
| 21 | Riverside | | | | | | | | Atlanta Constitution. | A door shook and a meeting broken up. |
| 22 | Salem | Lee | 32 40 | 85 16 | | | | | G. E. Weber | |
| 23 | Scottsborough | Jackson | 34 42 | 85 59 | 2 | SE. to NW | | | W. A. Anderson | Mountainous. |
| 24 | Selma | Dallas | 32 26 | 87 00 | | E. to W | | | Montgomery Daily Dispatch, September 1, 1886. | "Slight;" a little excitement. |
| | do | do | 32 26 | 87 00 | | | | | Florida Times-Union, September 1, 1886. | "Distinct shock;" buildings of more than one-story rocked and inmates rushed to the streets. |
| 25 | Shelby Iron Works | Shelby | 33 07 | 86 31 | 3 | SE. to NW | 3 | | Prof. A. A. Wright | Second most severe; total duration three minutes; Dr. Geddings says a roaring in the NE., then the SW. |
| 26 | St. Stephen's | Washington | 31 31 | 88 01 | | | | | J. A. Pelham, postmaster. | Not felt; soil sandy, clay, or rock. |
| 27 | Turkeytown | | | | | | | | I. C. Russell | Intensity about the same from Lookout Mountain to Villa Rica. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**ALABAMA—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | *m.* | *s.* | | |
| 28 | Tuscaloosa | Tuscaloosa | 33 08 | 87 33 | | | | | Atlanta Constitution, September 2, 1886. | Felt slightly at court-house; along ridge facing river quite severe; women and children left houses screaming, blinds were shaken off, chimneys rocked, and walls cracked. |
| 29 | Tuskegee | Macon | 32 24 | 85 41 | | | 1 | | Montgomery Daily Dispatch, September 1, 1886. | Beds shook, windows rattled, and cradles rocked; people rushed frantically from church; generally felt. |
| 30 | Union Springs | Bullock | 32 06 | 85 42 | 2 | | | | J. L. Moultrie | First lasted one-half minute; constant rattling of windows; interval ten or fifteen seconds; second lasted two seconds (Alabama weather service), "slight." |
| 31 | University | Tuscaloosa | | | 3 | E. to W | 5 | | J. C. Perkins | Alabama weather service; "severe;" soft earth, far above underlying rocks; no special barometric disturbance noted; tremor, ending with oscillations, accompanied by low rumbling; third most severe, lasting fifteen seconds; tops of chimneys thrown down, brick walls cracked, plastering dislodged, door bells rung, doors opened, and clocks stopped. |
| 32 | Valley Head | De Kalb | 34 36 | 85 34 | 1 | NE. to SW | 1 | | E. P. Nickolson | Alabama weather service; duration perhaps one minute; two lighter shocks felt at midnight and 2 a. m.; rumbling; windows and dishes rattled, furniture rocked violently, hanging lamps swung, buildings creaked; people very much frightened; no damage. |
| 33 | Wetumpka | Elmore | 32 33 | 86 09 | | | | | Montgomery daily, September 1, 1886. | "Distinct shock;" much excitement. |

**ARKANSAS.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Augusta | Woodruff | 35 17 | 91 18 | 2 | E. to W | | 8 | W. W. Folsam | Duration, first shock, five seconds; second, three seconds; no noise; undulatory. |
| 2 | Devall's Bluff | Prairie | 34 48 | 91 25 | | E. 10° N | | 4 | A. W. Lory | One very distinct shock and two or three very light tremors; total duration four seconds; house on bluff 18 feet above river valley; broken clay; no rock. |
| 3 | Fayetteville | Washington | 36 03 | 94 10 | | | | | Prof. G. W. Purenton | Not felt. |
| 4 | Hampton | Calhoun | 33 31 | 92 24 | | | | | L. G. Tomlinson, postmaster. | Do. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**ARKANSAS—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Duration. | Direction. m. | Direction. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | | | | |
| 5 | Helena | Phillips | 34 33 | 90 32 | 2 | | | | J. B. Miles | Interval one minute; first shock lasted about one second; no noise; felt throughout this "section." |
| | ......do | ....do | 34 33 | 90 32 | 3 | E. to W | | | New Orleans Democrat, September 2, 1886. | |
| 6 | Jonesborough | Craighead | 35 51 | 90 39 | 1 | | | 30 | J. W. Owens, postmaster. | Very light; noticed by a few upstairs; not felt on ground floor; no noise. |
| 7 | Little Rock | Pulaski | 34 46 | 92 13 | | | | | W. S. Thomas | Not felt. |
| | ......do | ....do | 34 46 | 92 13 | | | | | G. R. Brown, president Gazette Printing Company. | Do. |
| 8 | Monticello | Drew | 33 37 | 91 45 | | | | | Z. E. Kerr, postmaster. | Do. |
| 9 | Osceola | Mississippi | 35 43 | 89 57 | | | | | A. J. Nothy | Facts obtained from others. |
| 10 | Pocahontas | Randolph | 36 16 | 90 57 | | | | | S. T. Thompson, postmaster. | Not felt. |
| 11 | Sans Souci | Mississippi | 35 38 | 89 57 | 2 | | | | A. J. Nothy, United States assistant engineer. | On steamer, tied to bank, in Mississippi River; the steamer (heading west) lurched sidewise, listing towards the south; a second and lighter shock also struck her. |
| 12 | Van Buren | Crawford | 35 26 | 94 19 | | | | | Louis Grof | Not felt in this section. |

**CONNECTICUT.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Duration. | Direction. m. | Direction. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Central Village | Windham | 41 44 | 71 57 | | | | | W. M. D | Not felt. |
| 2 | Clark's Falls | New London | 41 27 | 71 52 | | | | | W. M. D | Do. |
| 3 | Colchester | ....do | 41 35 | 72 20 | | | | | W. M. D | One man thought he felt it. |
| 4 | Collinsville | Hartford | 41 41 | 72 57 | | | | | W. M. D | Not felt. |
| 5 | Durham | Middlesex | 41 28 | 72 42 | | | | | C. G. Rockwood, jr | Do. |
| 6 | Hartford | Hartford | 41 46 | 72 42 | 2 | | | | Hartford Courant, September 2, 1886. | Very distinct in some parts of city, but unobserved in others; felt by a man reading and not by others in the same room; the second shock rattled picture-frame; no noise. In another house a rumbling was heard, followed by swaying of the house, which moved chairs, stopped clock, and rattled two suspended triangles. At a third house a vase was upset and one party nauseated. Chandeliers swung in some instances; not generally noticed. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**CONNECTICUT—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | m. | s. | | |
| | Hartford | Hartford | 41 46 | 72 42 | | SW. to NE | | | A. H. Eddy | Jarring and loud rumbling; swung pendants and cracked plastering; house located on clay mixed with sand; had retired on second floor. |
| | ......do | ... do | 41 46 | 72 42 | | E. to W | | | E. M. White | Thermometers on wall swung 2 inches; crib also swung; accompanied by rumbling; noted by few. |
| 7 | Jewett City | New London | 41 37 | 72 01 | | | | | W. M. D. | Felt. |
| 8 | Middlebury | New Haven | 41 32 | 73 08 | | | | | W. M. D. | Not felt. |
| 9 | Middletown | Middlesex | 41 32 | 72 40 | | | | | W. N. Rice | Vague rumors that shock was felt; nothing definite. |
| 10 | New Haven | New Haven | 41 18 | 72 57 | 1 | NW. to SE | | 80 | Associated Press | Effects very sharp and noticeable throughout the city; buildings shaken and people badly frightened; in upper stories some made seasick, chandeliers shaken, pendants and picture-frames set swinging, and billiard balls set rolling; many rushed from tall buildings in their night clothes. At Signal Service office, on top a seven-story building, the shock was marked, and many were made ill by the rocking. |
| | ......do | ....do | 41 18 | 72 57 | 2 | NW. to SE | | 80 | Signal Service observer | Interval sixteen and one-half minutes; no noise; second shock slight. |
| | ......do | ....do | 41 18 | 72 57 | 1 | | | | J. Willcox | Was not awakened by shock. |
| 11 | New London | New London | 41 22 | 72 07 | | | | | Signal Service observer | Slight; some report that they heard low rumblings three times. |
| 12 | Quarryville | Tolland | 41 47 | 72 27 | | | | | W. M. D | Not felt. |
| 13 | Voluntown | New London | 41 34 | 71 54 | | | | | W. M. D. | Do. |
| 14 | Waterbury | New Haven | 41 33 | 73 03 | | | | | New York Herald, September 1, 1886. | Do. |
| 15 | Westbrook | Middlesex | 41 18 | 72 28 | 1 | | | | C. E. Bacon | Observer and wife had just retired when they felt the house shake. |
| 16 | West Haven | New Haven | 41 18 | 72 59 | | | | | New York Herald, September 1, 1886. | Not felt. |
| 17 | Winsted | Litchfield | 41 56 | 73 05 | 1 | | | | Rev. H. M. Kinney | Duration from one-half to three-fourths of a minute. |

**DELAWARE.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Delaware Breakwater. | | 38 49 | 75 07 | | | | | Associated Press | Very distinct shock; duration several seconds. |
| 2 | Fenwick's Island lighthouse. | | | | 1 | | 1½ | | J. D. Bennett, keeper. | Sitting in watch-room, felt sudden shake; generally felt; rattled tins and movable objects. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**DELAWARE—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | *m.* | *s.* | | |
| 3 | Middletown | New Castle | 39 26 | 75 44 | | | | | Wilmington (Del.) Every Evening, September 1, 1886. | Shaking felt in upper stories. |
| 4 | Milford | Kent | 38 55 | 75 25 | | | | | New York Times, September 2, 1886. | |
| 5 | New Castle | New Castle | 39 09 | 75 35 | | | | | Wilmington Every Evening, September 1, 1886. | Quite a number felt slight shock. |
| 6 | South Milford | Sussex | | | | | | | New York World | "In some dwellings lamps were overturned." |
| 7 | Rehoboth Beach | ....do | 38 43 | 75 05 | | | | | | |
| 8 | Seaford | ....do | 38 38 | 75 35 | 3 | | | | H. L. Phillips, postmaster. | Second heaviest, and lasted about one minute; third light; no noise; felt by majority; windows rattled, chairs rocked, beds shook, chandeliers swung; people frightened generally. |
| 9 | Wilmington | New Castle | 39 44 | 75 32 | | N. to S | | 2 | Associated Press | "Very slight;" sleepers awakened, houses trembled, windows rattled, and furniture shook. |
| | .....do | ....do | 39 44 | 75 32 | | | | | Wilmington Every Evening, September 1, 1886. | Very light shock, and felt by few. |
| | ......do | ....do | | | | | | | Henry Reeves | Of six persons sitting in parlor none noticed it; one lady afterward spoke of noticing it. |
| | ......do | ....do | 39 44 | 75 32 | 2 | SE. to NW | | | H. T. Gause, of Harlan. | Duration, first shock, forty seconds; end of tremors, three minutes; second, twenty seconds; second less severe; no noise; felt on hills and ridges of city. |

**FLORIDA.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration (m.) | Duration (s.) | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Altamonte | Orange | 28 39 | 81 25 | | NE. to SW | | 15 | V. E. Lucas, farmer | Fair observation; rumbling followed by quite severe shock; direction shown by movement of water in tub; duration not over fifteen seconds. |
| 2 | Apalachicola | Franklin | 29 44 | 80 00 | 1 | | | | G. H. Ruge | Quite distinctly felt; clocks stopped; articles on wall appeared to swing 2 or 3 inches. Many thought they had vertigo; six men on ground floor, brick building, ran out; not felt in some places. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**FLORIDA—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | m. | s. | | |
| | Apalachicola | Franklin | 29 44 | 80 00 | | NE. to SW | | 45 | No name | No noise; rattling of crockery; suspended objects swung in some cases; number of clocks stopped; undulatory; animals showed some alarm. |
| 3 | Baldwin | Duval | 30 18 | 81 58 | 3 | | 5 | | Florida Times-Union, September 1, 1886. | "Three shocks distinctly felt;" shaking of houses and cars heard plainly. |
| 4 | Bartow | Polk | 27 52 | 81 57 | | | | | New York Sun | In bed, and awakened by shock; swaying and rattling. |
| 5 | Beauclerc | Duval | 30 14 | 81 39 | 4 | E. to W | | | F. C. Sawyer | House rose and fell in waves, passing east; rumbling; poultry and dogs alarmed and clamorous. |
| 6 | Callahan | Nassau | 30 33 | 81 51 | 4 | | | | Florida Times-Union, September 2, 1886. | "Very severe;" in rickety house, which cracked and swayed as if it would fall; shocks at intervals of two, three, and twenty minutes; second, third, fourth shocks much lighter than first; no damage. |
| 7 | Cape Canaveral Lighthouse. | Brevard | 28 28 | 80 31 | | | 1 | | G. M. Quarterman, keeper. | Clock stopped. |
| 8 | Cedar Keys | Levy | 29 12 | 83 01 | | SE. to NW | | | W. W. Thomas, sergeant Signal Corps, U. S. A. | A slight trembling, increasing until it became regular, and houses and other objects swayed with clock-like regularity; standing cars moved to and fro, and wall ornaments fell; many made dizzy and sick; swaying felt one and one-quarter minutes, followed by trembling similar to beginning, for twelve and one-quarter minutes. |
| | ......do | ....do | 29 12 | 83 01 | | | | | Signal Service observer | "Heavy and distinct shock." |
| | ......do | ....do | 29 12 | 83 01 | | | | | Florida Times-Union, September 1, 1886. | Special, August 31, 9 p. m.—Heavy and distinct shocks being felt; houses and earth trembling violently and standing cars moving; people excited. |
| 9 | Cedar Keys Lighthouse. | ....do | 29 06 | 83 04 | 2 | | | | A. D. Hobday, keeper. | Interval about one minute. |
| 10 | Center Hill | Sumter | | | 2 | | | 6 or 7 | D. P. Ingraham | Two distinct shocks, two or three seconds apart, second much severer; no noise; other observations, duration five or six seconds. |
| 11 | Chaffin | Santa Rosa | | | 1 | | | 45 | T. B. Page | Felt in the house, very light; noticed by few; duration perhaps forty-five seconds. |

*Report of earthquake observations, earthquake of August* 31. 1886—Continued.

**FLORIDA—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | m. | s. | | |
| 12 | Chaseville | Duval | 30 22 | 81 25 | 3 | SE. to NW. | | | Florida Times-Union, September 3, 1886. | Ceiling appeared to move; lanterns and other suspended objects oscillated forcibly; crockery rattled loudly and every loose article shook; felt as if on moving ship; house trembled and undulated, apparently from end to end; lasted over a minute; was followed at intervals of some minutes by two or more less severe: direction, SE. to NW.; inmates of another house, in bed, in upper room, rushed to lower floor; commotion in fowl-yard, caused by fowls being shaken from roost: plastering considerably damaged; other plastered houses in vicinity damaged. (E. S. B.) |
| 13 | Crescent City | Putnam | 29 24 | 81 33 | | | | | ...do | Vibrations very distinct and lasted almost two minutes; interval, ten minutes; second, less violent but longer; third, slight, undulatory; many alarmed; several seasick. |
| 14 | Daytona | Volusia | 29 09 | 81 06 | | N. to S. | | 30 | Halifax Journal (Daytona). | Low rumbling; artesian or flowing wells greatly agitated; duration, about thirty seconds. |
| 15 | De Land | ...do | 29 04 | 81 21 | 2 | | 5 | | Florida Times-Union, September 9, 1886. | People thoroughly frightened; two distinct tremors, lasting five minutes, accompanied by rushing noise in the air as of strong gale, but without the effects of a storm; buildings shook and trembled, doors and windows rattled, and inmates rushed to the street; no sink-holes formed. |
| 16 | Ellaville | Madison | 30 23 | 83 12 | 2 | | | | Florida Times-Union, September 1, 1886. | Houses rocked very distinctly; a swinging of three motions a second; lasted ninety seconds; interval, five minutes; second, slighter. |
| 17 | Enterprise | Volusia | 28 51 | 81 18 | 1 | | | | ...do | "A severe shock is being felt as I write." (J. M.) |
| 18 | Esmeralda | | | | 1 | | | | W. S. Turner | Shock felt by most persons. |
| 19 | Eustis | Orange | 28 57 | 81 41 | 1 | | | | T. Wallace | Soil sandy. Sitting in chair, which seemed to be carefully lifted as by motion of wave swell; hanging lamp swung 3 inches from center; bird-cage swung. |
| 20 | Fernandina | Nassau | 30 30 | 81 27 | 3 | | 15 or 20. | | Florida Times-Union, September 3, 1886. | First shock very severe; buildings rocked and reeled like drunken men; second shock light; third, lighter; fourth shock, six or seven hours later, of same force as third; total duration, fifteen or twenty minutes; large meteor in SW. seen to gradually disappear. |
| 21 | Fort Meade | Polk | 27 45 | 81 48 | 4 | N. to S. | | | Signal Service observer | "Slight shocks," about four seconds each. |

*Report of earthquake observations, earthquake of August 31, 1886*—Continued.

**FLORIDA—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | m. | s. | | |
| 22 | Fowey Rocks Light house. | Dade | 25 36 | 80 06 | | | | | J. J. Lanier, keeper | Light-house trembled violently on the night of August 31. |
| 23 | Gainesville | Alachua | 29 39 | 82 19 | | | | | Florida Times-Union | Felt throughout the city; many alarmed, and those in bed thought it burglars; brick buildings very perceptibly rocked and swayed; frames, especially the smaller ones, shook and jarred very much, as if suddenly pried up by lever; joists and rafters shaking and cracking. A "prominent citizen" jumped from bed, seized gun, and ran out to see who was upsetting his house. Mr. Bell says two distinct shocks; court-house groaned and shook, lamps swayed E. to W., and clock stopped at his house in East Gainesville; next door to us fowls shaken off roost. Country colored people said "large hole" had fallen in near them. |
| 24 | Gulf Hammock | Levy | 29 15 | 82 44 | 2 | | | | Florida Times-Union, September 5, 1886. | Two distinct shocks; houses shook, windows rattled, and swinging lamps oscillated like pendulums. |
| 25 | Hawk's Park | Volusia | 29 00 | 80 55 | | | 2 | | Florida Times-Union, September 2, 1886. | "About as severe as the one seven or eight years ago." |
| 26 | Highland | Clay | 30 07 | 82 02 | | | | 40 to 60 | Florida Times-Union, September 1, 1886. | No damage; houses severely shaken; water 10 inches from top of railroad tank thrown out into the road; great excitement and alarm. |
| 27 | Higley | Orange | 28 51 | 81 46 | 3 | N. to S. | | 30 to 40 | W. Page | First, N. to S.; second, E. to W.; total duration, thirty to forty seconds; peculiar condition of atmosphere; strong undulation felt; floor, table, and furniture had corresponding motion; lamp on center of table nearly toppled over; three distinct shocks; a few cracks in walls of some houses; timbers settled an inch or two in others. |
| 28 | Jacksonville | Duval | 30 19 | 81 39 | | | | 30 | Associated Press, September 2, 1886. | "Quite severe," and felt as far south as Bartow. |
| | ......do | ....do | 30 19 | 81 39 | | | | 5 | Chicago Inter-Ocean, September 4, 1886. | "Distinct shock;" great excitement. |
| | ......do | ....do | 30 18 | 81 39 | 5 | N. to S. | | | J. Hensien | Two shocks, N. to S.; two light shocks seventeen minutes later. |
| 29 | Key West | Monroe | 24 30 | 81 48 | | | | | H. Crain | "I think there was a shock, a mere tremor, which escaped intelligent observers." |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**FLORIDA—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | *m.* | *s.* | | |
| 30 | Lake Annie | Orange | 28 45 | 81 25 | 2 | | | | Florida Times-Union, September 5, 1886. | Two heavy and very distinct shocks; second, hardest; interval, a few seconds; houses rocked and pictures swung; rattle of dishes heard in adjoining room. |
| 31 | Lake City | Columbia | 30 11 | 82 35 | | | | | Florida Times-Union, September 3, 1886. | Self and friend occupying seat between two large oaks overlooking lake; each thought the other rocking seat; water on lake greatly disturbed; oaks shook, rumbling and noise throughout grove as of a giant shaking the oaks; unprecedented scene of prayer at revival after shock: entire town "shaken up;" in some instances plastering fell from ceilings; a "general shout" in the colored settlement. |
| 32 | Lake Como | Putnam | 29 28 | 81 34 | | | | | do | "A slight shock." |
| 33 | Lake Helen | Volusia | 28 59 | 81 14 | | | | | B. H. Wright | Several shocks; distinctly felt and noticed by every one in Volusia County; two new houses plastered at the same time, same plasterer, 2 rods apart, one uninjured, much plastering shaken from other; low rumbling, intensity according to location. |
| 34 | Lake Hollingsworth | Polk | 28 01 | 81 57 | | E. to W | | | Florida Times-Union | In my house. 75 feet above lake, plastering cracked in all the rooms, and in bath-house on lake, with two windows, every pane of glass broken. |
| 35 | Lakeland | do | 28 02 | 81 58 | | | | | D. P. Ingraham | |
| 36 | Lawty | Bradford | 30 02 | 82 06 | 3 | | | | Florida Times-Union, September 9, 1886. | Shock lasted one-half minute, followed by two slight pulsations; vibrations in line of "magnetic meridian." Houses standing high on stilts performed the "Shanghai" waltz. |
| 37 | Leesburgh | Sumter | 28 50 | 81 53 | | | | | Florida Times-Union, September 5, 1886. | Slight shock; many frightened, and some young men thought they had "fit" or "vertigo;" physician ran down-stairs, fearing brick (building would fall. |
| 38 | Limona | Hillsborough | 27 58 | 82 13 | | | | | Signal Service observer | Apparently not felt. |
| 39 | Live Oak | Suwannee | 30 18 | 83 00 | | | | | Savannah Morning News, September 2, 1886. | Sensibly felt; no damage. |
| 40 | Macienny | Baker | 30 13 | 81 52 | 2 | | | | Florida Times-Union, September 1, 1886. | Number of residences badly shaken; occupants rushed into the streets and yards; sound distinctly heard a minute before first shock; interval, a few seconds; duration of each, one minute. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**FLORIDA—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | m. | s. | | |
| 41 | Manatee Village | Manatee | 27 33 | 82 33 | | | | | Signal Service observer | Several shocks. |
| 42 | Minneola | Sumter | 28 34 | 81 40 | | | | | Florida Times-Union | Many rocked out of bed; no damage except loosening of two joints of smoke-stack. |
| 43 | Monticello | Jefferson | 30 33 | 83 51 | 1 | E. to W | | | Florida Times-Union, September 3, 1886. | Slight shock, lasting a few seconds; houses vibrated E. to W., and windows and blinds rattled. |
| 44 | New Smyrna | Volusia | 29 03 | 81 03 | | ...do | | 30 | J. Y. Detwyler | Clocks on main-land facing E. or W. did not stop, those N. or S. did. |
| 45 | Norwalk | Putnam | 29 26 | 81 45 | | E. to W | 5 | | Florida Times-Union, September 3, 1886. | Quite severe; rumbling increasing until houses shook and windows rattled; undulatory. |
| 46 | Olustee | Baker | 30 11 | 82 30 | | | 1 | | Florida Times-Union, September 1, 1886. | "Rather severe;" undulatory; shook buildings; shock preceded by roaring. |
| 47 | Orange Heights | Alachua | | | 1 | | | | F. W. Belmer, postmaster. | Felt by majority of people. |
| 48 | Orlando | Orange | 28 33 | 81 24 | | | 1 | | Florida Times-Union | Chandeliers swayed and rattled; broke up a meeting; stampede at another. |
| | ...do | ...do | 28 33 | 81 24 | 1 | E. to W | | | J. T. Berks, superintendent of schools. | Buildings rocked; no noise; citizens excited. |
| 49 | Paisley | ...do | | | 2 | ...do | | | Florida Times-Union | Distinct shocks; first most felt; houses moved visibly E. to W. |
| 50 | Pensacola Light-station. | Escambia | 30 25 | 87 13 | 1 | | 3 or 4 | | No name | Rumbling; tremor; lens vibrated from side to side. |
| 51 | Quincy | Gadsden | 30 36 | 84 35 | | | | | Weekly Floridian | Considerable excitement; a congregation dispersed. |
| 52 | Rosetta | Alachua | | | 3 | N. to S | | 20 or 25 | H. V. Noszky | A tremor, then an undulation; water spilled on south side of tumbler; wall-paper cracked considerably; no noise. |
| 53 | St. Augustine | St. John's | 29 54 | 81 19 | | | | | Florida Times-Union | |
| 54 | St. Augustine Light-tower. | ...do | 29 53 | 81 16 | | | | | Light-House Board | Vibration of considerable energy; no noise. |
| 55 | Sanderson | Baker | 30 15 | 82 15 | 1 | | 3 | | Florida Times-Union | A heavy, distant rumbling, followed by severe shock; houses shook and bells rang. |
| 56 | Sanford | Orange | 28 48 | 81 20 | 3 | | | | H. Pennywith, sergeant Signal Corps (Signal Service observer). | Noise as of a rushing wind; chandeliers and other suspended objects swung. |
| | ...do | ...do | 28 48 | 81 20 | 2 | | | 30 | C. F. Sweeney, Western Union Telegraph operator. | Both very heavy; windows and fixtures rattled, and everything vibrated perceptibly. |
| | ...do | ...do | | | 3 | | | 10 | Signal Service observer | Noise as of a rushing wind. |

*Report of earthquake observations, earthquake of August 31, 1886*—Continued.

**FLORIDA—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | *m.* | *s.* | | |
| 57 | Satsuma | Putnam | 29 32 | 81 41 | 1 | S. to N | | | Florida Times-Union, September 3, 1886. | "Slight shock." |
| 58 | Sorrento | Orange | 28 49 | 81 33 | | | | | Florida Times-Union, Septemper 2, 1886. | Many frightened; thought to be an earthquake. |
| 59 | Spring Garden | Volusia | 29 07 | 81 24 | | | | | ......do | Heavy subterranean rumbling; heaviest at a store, where canned goods fell from shelves and swinging lamps swung enough to put lights out; 20 yards from store ground caved in 10 feet, in circle 30 feet in diameter, leaving cracks around it 12 inches wide, from 10 to 50 feet long. |
| 60 | Starke | Bradford | 29 57 | 82 07 | | | 2 | | Florida Times-Union, September 1, 1886. | "Violent shock;" houses and chandeliers shook; inmates of brick buildings rushed to the streets. |
| 61 | ......do | ....do | 29 57 | 82 07 | 2 | | | | J. P. Pratt, civil engineer. | Peculiar atmospheric effect at sundown, NNE. to SSW.; shortly after, severe shock E. to W. and tremors till daylight; subsoil, sandy clay; some say roaring; good observer says very peculiar rumbling after first shock; observer in bed; foot of bed raised, then head, and repeated; ran out of room; house shook violently; duration short; retired again; after interval some minutes rather severe oscillating, lasting many seconds. |
| 62 | Suwannee | Suwannee | 30 24 | 82 57 | | | | | Florida Times-Union, September 3, 1886. | Duration one minute or more; rumbling; blinds trembled, building shook violently; generally felt. |
| 63 | Switzerland | St. John's | | | 5 | E. to W | | | Florida Times-Union, September 5, 1886. | Steady shocks; first most severe and lasted thirty seconds, and shook windows and pictures; preceded by slight rumbling in river. |
| 64 | Tallahassee | Leon | 30 25 | 84 16 | | | | | Florida Times-Union | Quite severe; no damage, except to plastering; observer leaning against pillar of house, which swayed considerably; house creaked and inmates left building. |
| | ......do | ....do | 30 25 | 84 16 | | | | | J. Kost, LL. D | Was informed that on lake, 3 miles south, wave 5 feet high was caused by shocks, and rolled eastward, washing up on the shore. |
| 65 | Tampa | Hillsborough | 27 59 | 82 24 | | | | | D. P. Ingraham | Sleepers awakened, some feeling nausea; in upper part of county a sink formed on night of August 31, said to be 100 feet across and 30 feet deep. |
| 66 | Waldo | Alachua | 29 48 | 82 12 | | | | | Florida Times-Union, September 1, 1886. | Sensibly felt; houses rocked; furniture disturbed. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**FLORIDA—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | | | | |
| 67 | Wellborn | Suwannee | 30 13 | 82 48 | | | | | Florida Times-Union, September 2, 1886. | Very sensibly felt; houses, lamps, and crockery shaken, and ceiling cracked; clock stopped and sleepers awakened. |
| 68 | White Sulphur Springs | Clay | 29 58 | 81 39 | 3 | N. to S. | | | do | Intervals, ten and five minutes; third barely perceptible; buildings shook; lamps swung 6 inches from perpendicular, N. to S.; inmates left buildings. |
| 69 | Zellwood | Orange | 28 45 | 81 39 | 2 | NE. to SW. | | 40 | R. G. Robinson, real-estate agent. | Preceded by rumbling and accompanied by louder rumbling; windows rattled; house swayed NE. to SW., as agreed to by all; all nauseated; decidedly undulatory. |

**GEORGIA.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Adairsville | Bartow | 34 23 | 84 52 | 3 | NW. | | | H. D. Capers | Shock very violent, as if the house were about to be knocked from under him, followed by a sinking sensation; complaints of nausea. |
| 2 | Americus | Sumter | 32 04 | 84 14 | 4 | | 1 | | | People indoors were startled by the rattling of windows, followed by a decided trembling of the buildings and a swaying motion; this was repeated three times, lasting probably a minute each time; there was no general panic, however; shocks preceded by a low rumbling noise, like a railway train in the distance; no damage done. |
| 3 | Arcola | Bulloch | 32 28 | 81 52 | | | | | Savannah Morning News. | Terrible earthquake; so severe that we apprehended the loss of our houses; people filled with dismay. |
| 4 | Athens | Clarke | 33 55 | 83 22 | 4 | | 2 | | W. Mayfield | Houses considerably rocked, giving fear that it would be disastrous; meetings broken up in confusion; negroes thoroughly terrified. |
| 5 | Atkinson | Wayne | | | | | | | Savannah Morning News. | Preceded by a low rumbling as a distant railway train; soon the lamp began to rattle, and the whole house was in a confused din of shaking doors and windows, jingling glass, quivering chairs, etc.; outside the ground quivered and swayed and the trees rustled. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**GEORGIA—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | m. | s. | | |
| 6 | Atlanta | Fulton | 33 46 | 84 20 | | | | | | At five minutes before 9 o'clock Atlanta was violently shaken up, people rushing into the streets in indescribable confusion, each looking for an explanation from the others. A second and third shock came, exceedingly violent, in the city that was now full of alarmed people. Soon telephone messages came in from the West End, Marietta, Decatur, and other outlying towns all showing that the earthquake had shaken the people out of bed. One house on Marietta street was shattered to pieces. An assembly of Knights of Labor, five hundred in number, adjourned in confusion. The chimneys on the six-story *Constitution* building all fell, whereupon the forty compositors sought the street, with their "sticks" in their hands. All over the city window-glass is broken, chimneys knocked down, and dishes and clocks smashed to pieces. The streets at 10 o'clock are full of people, who fear to return to their houses. |
| 7 | Augusta | Richmond | | | | | | | | See Chap. V. |
| | do | do | | | | | | | H. W. Grady | The Augusta people find it impossible to understand how the Atlanta people treat the earthquake so lightly. The truth is, the Atlantean can not appreciate the terror of the situation until he reaches Augusta, which may be said to be on the outer edge of the region where the earthquake was not only serious but altogether the most awful experience of the century. |
| 8 | Bainbridge | Decatur | 30 55 | 84 36 | | N. to S. | | | | A roaring sound unlike thunder; clocks stopped; houses swayed; bells rang; doors were slammed, and hanging lamps violently swung. |
| 9 | Baxley | Appling | 31 44 | 82 21 | | | 1 | | Savannah Morning News. | A very violent and alarming shock. |
| 10 | Beach Springs | | | | | | | | Atlanta Journal | At the Baptist church great confusion prevailed; it trembled greatly. |

*Report of earthquake observations, earthquake of August* 31,1886—Continued.

**GEORGIA—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| 11 | Brunswick | Glynn | 31 12 | 81 28 | | | | | Savannah Morning News. | A severe earthquake. The first indication was a tremor, followed by a violent shock, which had the effect of emptying every habitation of its inmates. Great excitement prevailed, but no damage reported. The shock was felt in equal severity at all points on the Brunswick and Western Railroad. |
| 12 | Butler | Taylor | 32 35 | 84 14 | | | 2 | | N. Crossman | A violent shock, lasting minutes, creating very great excitement. It was followed by others. |
| 13 | Cairo | Thomas | 30 53 | 84 12 | | | | | Savannah Morning News. | Considerably shaken. |
| 14 | Calhoun | Gordon | 34 36 | 84 54 | | | | | do | People left their houses, thinking them about to fall. |
| 15 | Carrollton | Carroll | 33 42 | 85 01 | | E. to W | 1 | | do | Plastering broken and brick walls cracked. |
| 16 | Chauncey | Dodge | 32 05 | 85 00 | | | 1 | 30 | do | People ran out of their houses, fearing they would fall; bottles and small things shaken from shelves. |
| 17 | Climax | Decatur | 30 53 | 84 27 | | | | | do | Severely felt here. |
| 18 | Cochran | Pulaski | 32 21 | 83 19 | | E. to W | 1 | 30 | Q. L. Harvard | Rumbling sound; floor, chairs, and tables seemed to swing; hanging lamps oscillated; people left houses in fright. |
| 19 | Cockspur Island | | 32 04 | 80 50 | | | | | Light-keeper | Tower of light-house violently swayed. |
| 20 | Coll's Island | Liberty | | | | NE | | | J. A. M. King | Began with rushing, rumbling sound, which increased until house violently rocked; furniture rattled; lamp on the table rocked and tottered; the family left the house in fear; birds and animals much alarmed; fowls shaken from their roosts. |
| 21 | Columbus | Muscogee | 32 32 | 84 55 | 10 | | 3 | | United Press | People much frightened; many ran from their houses; reports from all neighboring towns in Georgia and Alabama show that they felt the shock, and they are telegraphing to ascertain its extent; several chimneys were thrown down. |
| 22 | Covington | Newton | 33 35 | 83 48 | | E. to W | 1 | | Atlanta Constitution | People rushed from their beds in their night-clothes; several chimneys fell; lamps and dishes were thrown from tables. |
| 23 | Darien | McIntosh | 31 24 | 81 27 | | | | 30 | | A small house demolished. |
| 24 | Diamond | Gilmer | 34 41 | 84 11 | 3 | | | | W. W. Kinzey | Strongly felt, but along a neighboring ridge for a distance of 7 miles it was not perceived; no noise. |

*Report of earthquake observations, earthquake of August 31, 1886*—Continued.

**GEORGIA—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | m. | s. | | |
| 25 | Douglas | Coffee | 31 31 | 82 50 | 1 | | 1 | | B. Peterson | Felt by a majority of persons; windows and crockery rattled; no noise. |
| 26 | Eastman | Dodge | 32 10 | 83 06 | | | | | Savannah Morning News. | Caused many to leave their houses; great excitement prevails. |
| 27 | Eatonton | Putnam | 33 18 | 83 21 | 4 | | 2 | | ......do | Everybody frightened, especially the blacks; the tops of several chimneys shaken off, and plastering broken; one brick dwelling had its walls cracked. |
| 28 | Eden | Effingham | 32 11 | 81 21 | 5 | N. to S. | | | S. C. Smets | Loud rumbling sound; house swayed and rocked, the inmates running out in great terror. |
| 29 | Elberton | Elbert | 34 04 | 82 48 | 3 | E. to W. | | 40 | L. Dorman | |
| 30 | Fairburn | Campbell | 33 33 | 84 29 | | | 2 | | Savannah Morning News. | Houses shook and windows rattled as if a cyclone were raging. |
| 31 | Folkstone | Charlton | | | 5 | | | | ......do | People badly scared, but no damage done. |
| 32 | Forsyth | Monroe | 33 02 | 83 57 | 3 | | | | Atlanta Journal | Plastering fell from ceilings. |
| 33 | Fort Gaines | Clay | 31 34 | 85 00 | | | | | J. Conners | A very forcible shock. |
| 34 | Fort Valley | Houston | 32 33 | 83 52 | | | | | Atlanta Constitution | Felt. |
| 35 | Gainesville | Hall | 34 18 | 83 49 | 1 | E. to W. | | | C. B. La Hatte | Heavy shock, accompanied by a terrible roaring sound; great consternation. |
| 36 | Georgetown | Quitman | 31 50 | 85 04 | | | | | Atlanta Constitution | Very sensibly felt. |
| 37 | Greeneville | Meriwether | 33 02 | 84 40 | | | | | ......do | |
| 38 | Griffin | Spalding | 33 14 | 84 15 | | | 3 | | Savannah Morning News. | Windows rattled and houses moved visibly; panic in church. |
| 39 | Guyton | Effingham | 32 19 | 81 22 | 3 | | 1 | 30 | ......do | Great alarm and excitement, but no damage. |
| 40 | Halcyon Dale | Screven | 32 32 | 81 33 | | | | | ......do | Plastering and some chimneys fell, and everybody much excited, but no serious damage. |
| 41 | Hampton | Henry | 33 21 | 84 16 | 6 | NW | | | C. S. Cushing | |
| 42 | Hawkinsville | Pulaski | 32 17 | 83 28 | 3 | | 1 | 30 | J. Morgan | Sound like distant thunder, and shaking of the earth; no damage more serious than the shaking down of small articles. |
| 43 | Hephzibah | Richmond | 33 18 | 81 47 | 4 | E. to W. | 2 | | E. Cosgrove | Heavy, rumbling sound; undulatory motion; ceilings cracked and bricks fell from chimneys. |
| 44 | Hillis | Burke | | | | | 1 | | A. B. Hawley | First shock heavy, stopping a calendar clock, ringing bells, and shaking fowls from their roosts; joints in buildings cracked; motion undulatory. |
| 45 | Hogansville | Clinch | 33 10 | 84 46 | 1 | | 1 | | S. Smith | Felt very sensibly; no noise. |
| 46 | Irwinton | Wilkinson | 32 45 | 83 08 | | | | | Atlanta Constitution | Nearly all the clocks in town were stopped; one which had not been running was started by the shock. |
| 47 | Jasper | Pickens | 34 27 | 84 22 | | | | | ......do | No details. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**GEORGIA—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | | | | |
| 48 | Jesup | Wayne | 31 33 | 81 53 | 3 | | | | Savannah Morning News. | Houses rocked to and fro, and the greatest consternat on prevailed; the town is thoroughly alarmed and excited, but no damage is reported. |
| 49 | Kenna | Lincoln | | | | N. to S. | | | A. H. M. Laws | Houses shaken; doors and windows rattled; loud, rumbling noise, like distant thunder; nausea felt by many; shocks very violent. |
| 50 | Kingston | Bartow | 34 14 | 84 52 | | E. to W | | | F. R. Murray | Shocks very strong, shaking houses with great violence; decided undulatory motion. |
| 51 | La Grange | Troup | 33 02 | 84 58 | | | 1 | | Augusta Chronicle | A terrible shock, accompanied by a loud rumbling; buildings cracked, and chimneys also; terror reigns among the negroes, and the greatest excitement prevails among all classes. |
| 52 | Lawrenceville | Gwinnett | 33 57 | 83 56 | | | | | Atlanta Constitution. | Severe shocks; panic in the church. |
| 53 | Lexington | Oglethorpe | 33 51 | 83 07 | 4 | E. to W | | | Thomas Postley | Buildings rudely shaken, bricks thrown from chimneys, and plastering detached. |
| 54 | Longstreet | Pulaski | 32 23 | 83 16 | | | 3 | | T. N. Mason | Loud rumbling noise; house rocked to and fro and seemed to crack at every joint. |
| 55 | Lumber City | Telfair | 31 53 | 82 38 | | | 1 | | Savannah Morning News. | A tremendous shaking of the earth felt by all citizens of the place; houses cracked and rocked to and fro, frightening every one. |
| 56 | Macon | Bibb | 32 48 | 83 37 | 4 | | 1 | | Associated Press | Great excitement caused. The shock alarmed the people, causing them to rush into the streets expecting the houses to fall; it was especially severe in the upper portion of the city, near the cemetery; reports from towns near here say that the shocks were very severe, throwing articles to the floor, breaking plastering; a few chimneys in Macon were overthrown; no serious damage; negroes panic-stricken. |
| 57 | Madison | Morgan | 33 33 | 83 24 | | | | | Savannah Morning News. | Considerable excitement caused by a severe shock of earthquake, which lasted several minutes; no damage was done except a few bricks thrown from chimneys; some persons remained up all night through fright. |
| 58 | Midville | Burke | 32 50 | 82 09 | 3 | | 2 | | do | A terrible earthquake; it is reported as being a terrible shock 14 miles from here, in Emanuel County. |
| 59 | Milledgeville | Baldwin | 33 04 | 83 13 | | | | | S. B. Cameron | A forcible shock, creating great alarm and apprehension; rocking houses severely. |
| 60 | Mossy Creek | White | | | 3 | | | | J. M. Dorsey | Very forcible and alarming. |

*Report of earthquake observations, earthquake of August 31, 1886*—Continued.

**GEORGIA—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | *m.* | *s.* | | |
| 61 | New Holland | Hall | 34 21 | 83 46 | | | 2 | | F. Barclay | Overthrew some chimneys and rocked houses violently. |
| 62 | Newnan | Coweta | 33 20 | 84 45 | 2 | | | | Atlanta Journal | Two heavy shocks felt. |
| 63 | Owen's Ferry | Camden | 30 55 | 81 38 | | | 1 | | J. Caldwell | Severe earthquake; lamps rattled and joists cracked; buildings rolled so that it was difficult to stand. |
| 64 | Oxford | Newton | 33 38 | 83 46 | | | | | P. B. Wells | The whole surrounding country shaken severely, and everybody much alarmed. |
| 65 | Reynolds | Taylor | 32 35 | 84 05 | | | | | Atlanta Constitution. | Great consternation produced among all citizens; houses trembled violently; loud noises. |
| 66 | Rome | Floyd | 34 15 | 85 04 | | | | | Western Union Telegraph. | The earthquake shocks were very heavy here; great excitement prevailed and the streets were full of excited people; buildings shook violently. |
| 67 | Sandersville | Washington | 32 57 | 82 49 | | | | | Savannah Morning News. | A severe earthquake shock was felt here to-night, causing strong houses to rock and shake tremendously; great excitement. |
| 68 | Savannah | Chatham | 32 05 | 81 04 | | | 1 | 30 | | See Chap. V. |
| 69 | Scarborough | Screven | 32 40 | 81 49 | 6 | | | | W. Sullivan | Six shocks, two of them violent. We learn that a house near here was almost wrecked. |
| 70 | Shellman | | | | | | | | Atlanta Constitution. | Lamps, crockery, and other articles fell; fowls shaken from their roosts. |
| 71 | Smyrna | Cobb | 33 55 | 84 27 | | | | | Associated Press | Several shocks; no details. |
| 72 | Sparta | Hancock | 33 13 | 82 55 | | | | | Atlanta Constitution. | Very severe shocks. |
| 73 | Springfield | Effingham | 32 19 | 81 17 | | | | | A. G. Merrill | Severe shocks; pictures, glasses, etc., thrown from walls and broken; plastering cracked, and bricks thrown from chimneys. |
| 74 | Surrency | Appling | 31 39 | 82 12 | | | 3 | | Savannah Morning News. | A heavy shock. |
| 75 | Tallapoosa | Haralson | 33 48 | 85 12 | 4 | | 2 | | S. Card | Four severe shocks, creating great alarm. |
| 76 | Tennille | Washington | 32 55 | 82 45 | 2 | | 5 | | Savannah Morning News. | Heavy shocks, continuing five minutes; the earth moved very perceptibly; engines and cars moved visibly on the track. |
| 77 | Thomaston | Upson | 32 52 | 84 17 | | | | | Atlanta Constitution. | No details. |
| 78 | Thomasville | Thomas | 30 48 | 84 02 | | NE | | | Savannah Morning News. | Solid brick buildings were swayed, while crockery, pictures, etc., were shaken about considerably; the streets were rapidly filled by an excited population; many clocks were stopped. |
| 79 | Trefairville | Burke | | | | NE | 2 | | R. L. Rhodes | Heavy rumbling noise; bricks shaken from chimneys; undulatory motion very perceptible. |
| 80 | Tusculum | Effingham | | | | | | | H. L. Marsh | Several distinct shocks, the first rocking houses violently. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**GEORGIA—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | m. | s. | | |
| 81 | Tybee Island | | | | | | 2 | | Associated Press | Shocks extremely violent; the lantern and lenses in the light-house were broken, and the machinery of the lantern disarranged; the shocks here seemed to be even more violent than in Savannah. |
| 82 | Ty Ty | Worth | 31 31 | 83 40 | | | | | Savannah Morning News. | People all left their houses; glass and small furniture moved by the shock. |
| 83 | Union Point | | 33 34 | 83 00 | 2 | | 1 | 30 | Augusta Chronicle | No details. |
| 84 | Valdosta | Lowndes | 30 49 | 83 21 | | | | | Savannah Morning News. | Those who had retired were aroused by the trembling of their houses and the falling of plaster; it has created much excitement and uneasiness. |
| 85 | Walthourville | Liberty | 31 46 | 81 37 | 3 | N. to S. | 1 | 30 | J. L. Harden | Began with light trembling, increasing in intensity; no noises heard, or at least not noticed; wave-like motion. |
| 86 | Washington | Wilkes | 33 42 | 82 43 | 4 | NE | 2 | | W. B. Hurd | Powerful vibration of building, as if shaken by some great engine; bricks thrown from chimneys; loud rumbling or roaring sound. |
| 87 | Way Cross | Ware | 31 14 | 82 22 | 3 | | 1 | 30 | Savannah Morning News. | Buildings were badly shaken up, articles on the shelves of stores thrown down, and clocks stopped; the people are thoroughly alarmed, and the streets are full of excited residents. |
| 88 | Waynesborough | Burke | 33 05 | 81 57 | 3 | | | | Atlanta Journal | The negroes staid in the streets all night, singing and praying. |
| 89 | White Marsh Island | | | | 6 | | 1 | 30 | G. Treanor | Preceded by loud booming noise; the house seemed to be dancing a jig; furniture moved and windows much shaken; great consternation and fear. |

**ILLINOIS.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration (m.) | Duration (s.) | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Big Prairie | White | 38 08 | 88 07 | | | | | D. Berry, M. D. (from hearsay). | Movement very perceptible in house; unnoticed outside. |
| 2 | Bloomington | McLean | 40 30 | 89 01 | | | | | J. A. Miller, county superintendent. | Not felt. |
| | ......do | ....do | 40 30 | 89 01 | 2 | N. to S | | | Chicago Inter Ocean, September 1, 1886. | Chandeliers with four feet suspension swayed 3 to 4 inches N. and S.; desks and furniture swayed and buildings shook; some heard rumbling like empty barrel rolled on floor. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**ILLINOIS—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | *m.* | *s.* | | |
| 3 | Cairo | Alexander | 37 05 | 89 10 | | | | | Cincinnati Commercial Gazette, September 1, 1886. | Severest felt in many years; clocks stopped, buildings shook, chandeliers swung, and people generally left houses; no damage heard of. |
| | ...do | ...do | 37 05 | 89 10 | | | | 50 | Cairo Daily Argus, September 1, 1886. | "A severe shock;" undulatory, and if a little more severe would have shaken down houses; several large clocks stopped; chandeliers vibrated like pendulums; houses rocked and creaked, and many left them; a clerk reported thrown from his chair at Halliday Hotel; lamp chimney thrown off at St. James, and on Washington avenue above 10th houses settled considerably, breaking glass in front windows; duration variously estimated, and some say three distinct waves; no serious damage reported; Signal Service observations in upper story custom-house reports lasted fifty seconds; swayed building and rattled chandeliers; active movement of wires in office; felt dizzy and sick; people left building; ceiling cracked in post-office. |
| | ... do | ...do | 37 05 | 89 10 | | | | | Chicago Herald, September 2, 1886. | "Several clocks stopped." |
| 4 | Carlyle | Clinton | 38 39 | 89 24 | | | | | G. A. Beatie, superintendent of schools. | Not felt. |
| 5 | Carmi | White | 38 08 | 88 10 | 3 | | | | D. Berry, M. D. (from hearsay). | No noise; shocks four or five seconds apart; some say it lasted two or three seconds, others three minutes. On clay drift 50 feet above limestone. Not felt out of doors, nor on first floors, unless quietly reading; oil in lamp swayed; on second floor, brick building, printers alarmed at first shock and left building after second; type cases swayed lengthwise S. to N. |
| 6 | Carthage | Hancock | 40 24 | 91 06 | 1 | | 1 | 30 | G. M. Kellogg | Third story of brick building; felt distinctly by members of lodge; one shock, possibly more. In another lodge lamps swung and house vibrated. Party walking on street felt movement and suspected an earthquake. |
| 7 | Charleston | Coles | 39 32 | 88 12 | | | | | A. J. Funkhouser, superintendent of schools. | Several tremulous vibrations; no noise; duration, a few minutes; intensity, "between light and moderate." |
| | ..do | ...do | 39 32 | 88 12 | 1 | SW. to NE. | | | Signal-Service observer. | Felt by several, and lasted several seconds. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**ILLINOIS—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | m. | s. | | |
| 8 | Chicago | Cook | 41 52 | 87 37 | | W. to E | | 6 or 7 | Associated Press, September 1, 1886. | Erratic action of barometer at signal office; the sergeant's hands trembled violently, and for a moment he thought he was ill; rocking of large chair in middle of room; vibrations 3 or 4 to the second; barometer rose $\frac{1}{100}$ of an inch in 7 minutes; soon after shock it marked 30.17, and rose rapidly. Not generally felt except in upper stories of tall buildings. Telephone communication cut off for a time. |
| | do | do | 41 52 | 87 37 | | | | | New York Times, September 1. | "A deafening sound." In the Leland Hotel women cried, yelled, and fell to the floor in prayer; building shook perceptibly. The public library in City Hall was wrenched out of all semblance to architecture. At Government building clerks thought there were six or seven shocks, lasting 3 or 4 seconds; windows banged in frames six or seven times, and building shivered; Signal-Service observer sitting writing at desk, head wabbled around; building quivered; waves seemed to pass from SW. to NE., at rate of three a second; duration, 6 or 7 seconds. No damage. Many dizzy. In some houses doors swung and pictures moved from wall. Intensity seemed equal throughout city. Number shocks variously estimated. |
| | do | do | 41 52 | 87 37 | | S. to N. | | 7 or 8 | Knoxville Journal and Louisville Commercial, September 1, 1886. | Most perceptible in tall buildings; Signal Service observer says direction seemed from S. to N. and the waves were three per second; no damage and no excitement. |
| | do | do | 41 52 | 87 37 | | | | | New York Tribune, September 2, 1886. | A slight tremor; scarcely perceptible rocking of large buildings; knowing of the earthquake elsewhere, evidence is ample of its effects here; in library, tables shook slightly and everybody with two exceptions hastened from building; in reading-room, suspended from ceiling of main library, floor swayed and half the readers ran out; the panic soon abated; not felt on lower floors City Hall; people affected with nausea in large buildings. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**ILLINOIS—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
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| | | | ° ′ | ° ′ | | | m. | s. | | |
| | Chicago | Cook | 41 52 | 87 37 | | | | | Chicago Herald, September 6, 1886. | Especially noticeable in upper stories of large and tall buildings; not felt on streets and lower floors; guests in the Leland were greatly terrified; some left rooms partially clothed, and women became hysterical and refused to return; some say the sensation was like seasickness and filled them with an indescribable horror; at the Beaurivage it was felt above third floor; on fifth floor a door-bell rang, and a billiard-player almost thrown down; on sixth floor a party sitting in rocking-chair felt it move and noticed table move; in a flat, plastering was thrown from ceiling and inmates nauseated; not felt at the Richelieu. |
| | ...do | ...do | 41 52 | 87 37 | | | | | Chicago Herald, September 1, 1886. | On ninth floor Pullman Building, waiter almost dropped tray of dishes; others in room felt movement distinctly, but not felt on lower floors. Reading-room, top floor City Hall, suspended by iron bars, swayed violently, and readers ran to the ground. Signal Service man reports: Queer action barometer for several hours previous and rising rapidly; was standing, felt body sway, felt momentary dizziness; wave passed from W. to E. and lasted six or seven seconds; three vibrations per second; barometer rose $\frac{1}{100}$ of an inch in seven minutes. Janitor reports building swayed; pictures clattered; walls and chairs rocked; family and self frightened. Manager Central Telephone station says: Sitting at desk, felt swaying, blinds moved slightly; some connecting pegs fell out; not felt by boys on feet. Tremont House, clerk in upper story, awakened by moving of bed; guests ran from rooms; large glass sky-light cracked; no other damage; felt distinctly throughout city. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**ILLINOIS—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
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| | | | ° ′ | ° ′ | | | *m.* | *s.* | | |
| | Chicago | Cook | 41 52 | 87 37 | | | | | Inter Ocean, September 1. | Perceptible, but not severe. At Signal Service office measure-box rocked and frames hanging on W. wall thrown forward with a jerk. Oscillation barometer quite noticeable; barometer stood $\frac{1}{100}$ of an inch higher than before shock for eight minutes; direction from W. to E.; duration seven seconds and three vibrations per second, each of which jarred observer in chair. Reading-room, fourth floor City Hall, suspended from ceiling in large gallery, 40 readers at tables; whole gallery swayed, and people rushed down-stairs; not felt in other parts City Hall. At Leland plainly felt, and guests ran from rooms into office. Felt slightly at Richelieu. Beaurivage Building shook above fourth floor; in several rooms plastering shaken from walls and ceiling. On ninth floor, Pullman Building, very perceptibly felt; glass and china jingled with a great clatter; no damage. At Commercial Hotel plainly felt; lady invalid thrown into violent convulsions. At Major Block, janitor and family at supper; dishes rattled and walls trembled; family left room thinking it an explosion; Judge Prendergast, sitting in parlor, felt house shake violently; felt by several in store, and a woman rushed out doors. |
| | do | do | 41 52 | 87 37 | | | | | S. Engel | Chandelier and rubber gas pipe for drop-light swayed for a long time; felt rocking-chair shake and newspaper sway in hand; peculiar feeling of dizziness. |
| | do | do | 41 52 | 87 37 | | N. and S. | | | Miss M. McBriggs | On third floor felt distinct swaying or undulation; no noise. |
| | do | do | 41 52 | 87 37 | | | | | W. R. Cooper | None in block felt it. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**ILLINOIS—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
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| 9 | Danville | Vermilion | 40 09 | 87 36 | 1 | | | | H. W. Beckwith | Daily News says: "A heavy shock, as if earth were creaking and shaking from a vast earthquake; stampede in Masonic lodge; building swayed several times, and some thought it on fire and giving way. Knights of Pythias felt it, but were so busy they did not notice it. Noticed in various parts of city." This is "too exaggerated." No physical shock; swaying was felt by a few in third stories; not felt on streets and first floors, but on second and third, lamps swayed and windows rattled; no noise; lasted a few seconds. |
| | do | do | 40 09 | 87 36 | 1 | | | | Chicago Inter Ocean, September 2, 1886. | "A perceptible shock;" no damage. |
| 10 | Decatur | Macon | 39 53 | 88 59 | | N. and S. | | | Associated Press | Shock felt quite sensibly; articles in dwellings shook and rattled, and business houses swayed slightly N. and S.; at a hotel guests ran into the streets; proprietor sought cellar to see if foundation was tumbling; no damage; some fright. |
| | do | do | 39 53 | 88 59 | | do | | | New York Sun, September 2, 1886. | |
| | do | do | 39 53 | 88 59 | | | | | New York World | |
| 11 | Effingham | Effingham | 39 09 | 88 33 | | | | | C. H. Kelly, postmaster. | Not felt. |
| 12 | Elgin | Kane | 42 04 | 88 16 | | | | | Chicago Herald, September 1, 1886. | Manager of Central Telephone Station, Chicago, said: "No one knew of shock at Elgin." |
| 13 | Evanston | Cook | 42 03 | 87 41 | | | | | do | Manager of Central Telephone Station, Chicago, said: "People were badly scared; stronger than at Chicago, as it moved chairs on first floors. |
| | do | do | | | 1 | S. to N. | | | William H. Lyford, M. D. | Gives observations of light-house keeper: Distinctly felt a throwing of his body to the S.; machinery for moving lantern stopped. |
| 14 | Greenville | Bond | 38 55 | 89 25 | | | | | Associated Press | Lively shocks at intervals of one-half a minute; buildings rocked; no damage. |
| | do | do | 38 55 | 89 25 | | | | | New York Sun, September 2. | Several shocks. |
| 15 | Hillsborough | Montgomery | 39 11 | 89 31 | | | | | J. E. Barrett, county superintendent. | "Not felt in this county." |
| 16 | Jacksonville | Morgan | 39 45 | 90 14 | | E. to W | | | Associated Press | Buildings vibrated E. to W., tables and other articles tipped, and people greatly frightened. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**ILLINOIS—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | | | | |
| | Jacksonville | Morgan | 39 45 | 90 14 | | | | | Chicago Inter Ocean, September 1, 1886. | "Small earthquake," which shook buildings and alarmed a number of people. |
| | ......do | ....do | 39 45 | 90 14 | | E. to W | | | New York Sun, September 2, 1886. | |
| 17 | Jefferson | Cook | | | 1 | | | 6 | E. G. Westlake | Good observation; clock stopped; water in bucket put in motion; vibrations distinctly felt. |
| 18 | Joliet | Will | 41 31 | 88 05 | | | | | R. L. Allen, postmaster. | Not felt. |
| 19 | Kankakee | Kankakee | 41 08 | 87 54 | | | | | J. H. Shaffer, postmaster. | Do. |
| 20 | Kewanee | Henry | 41 15 | 89 56 | | | | | G. F. Clark | Not felt in town. |
| 21 | Lewistown | Fulton | 40 24 | 90 10 | | | | | W. W. Hull, postmaster. | Not felt. |
| 22 | Lonisville | Clay | 38 50 | 88 32 | | | | | L. S. McKnight, superintendent of schools. | Second story two-story brick building; felt by only two men in county—one felt one very brief shock, the other two very brief and quickly following each other; both reside in town; no noise; felt only upstairs; windows rattled; chairs vibrated. |
| 23 | Marshall | Clark | 39 25 | 87 44 | 1 | | | 5 | H. V. Gard, connty superintendent. | Very light; felt by three only. |
| | ......do | ....do | 39 25 | 87 44 | | | | | D. P. Sanderson | Not felt. |
| 24 | Mount Vernon | Jefferson | 38 21 | 88 55 | | | | | W. T. Sumner, superintendent of schools. | None felt; if so, very slightly; a few unreliable persons claim to have felt it. |
| 25 | Murphysborough | Jackson | 37 49 | 89 20 | 2 | E. to W | 1 | | Associated Press | "Quite severe;" brick walls shook; glassware clinked, and hanging lamps swung like pendulums; fire-bell on court-house rang for a minute; in second story center brick block, a lodge assembled felt so violent rocking they rushed to the streets without hats; bar-keeper felt drunk and clung to his counter; suspended lamps swung E. and W.; some affected with great nausea. |
| 26 | Oakland | Coles | 39 42 | 88 05 | 2 | | | | W. J. Peak, M. D | Two shocks distinctly felt by many, especially upstairs; more severe than February 6; accompanied by a rumbling or roaring. |
| 27 | Olney | Richland | 38 46 | 88 06 | | | | | R. N. Slotter | Not felt. |
| 28 | Oregon | Ogle | 41 01 | 89 21 | | | | | C. T. Marsh | Do. |
| 29 | Pacific | Cook | 41 55 | 87 43 | | | | | E. G. Westlake | House shook slightly, dishes rattled, clock stopped, dipper in water pail considerably agitated. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**ILLINOIS—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | *m.* | *s.* | | |
| 30 | Paris | Edgar | 39 38 | 87 45 | | W. to E. | 1 or 2 | | A. J. Trogdon, ex-county judge. | Upstairs, two-story building, middle of block, writing on table; hand moved 2 inches, house swayed perceptibly and timbers creaked; not felt on ground, and not generally noticed in the county; plaster in room upstairs slightly cracked; all in Paris awake and upstairs felt it. |
| | do | do | 39 38 | 87 45 | 2 | E. to W. | | | A. Harvey, superintendent schools. | "Moderate" interval and duration a few seconds; several observations on direction; slight rumbling, doors rattled, chandeliers swung; very noticeable in third stories. |
| | do | do | 39 38 | 87 45 | | | | 2 | H. F. Nelson and others. | One party ran out of store alarmed at rattling of doors and violent swinging of chandelier E. to W.; another's chandelier swung N. to S., and another's chair swayed E. to W.; oil in lamp violently agitated; party seated in chair which rocked; clock pendulum agitated; dog frightened; a noise at places, but very slight; alluvial district, 600 feet above coal measures. |
| 31 | Pekin | Tazewell | 40 35 | 89 38 | 1 | | | | J. E. Terberg | Lasted a few seconds; barometer rising rapidly; very slight; noticed by several. |
| 32 | Peoria | Peoria | 40 42 | 89 36 | 1 | E. to W | 1 | | A. G. Palmer, Peoria, Decatur and Evansville Railroad Company. | Observation of S. M. Clarke; house 2 miles W. of city, 200 feet above river level; on first floor, in rocking-chair, which rocked E. and W. nearly; chandelier swung E. and W. nearly; no noise; a continuous rocking. |
| | do | do | | | | | | | do | Made diligent search; no one in city felt it. |
| 33 | Quincy | Adams | 39 56 | 91 22 | | | | | J. H. Richardson, postmaster. | Not felt. |
| 34 | Ridgway | Gallatin | 37 50 | 88 17 | 1 | | | 15 | A. T. Landerbough, farmer. | Preceded by roaring; houses trembled and vibrated slightly; dishes and canned goods rattled. |
| 35 | Salem | Marion | | | | | | | A. Hamilton, county surveyor. | "Exceedingly light;" duration "momentary;" noticed only upstairs by people on spring beds, etc.; undulatory; no noise. |
| 36 | Shelbyville | Shelby | 39 26 | 88 49 | | | | | Chicago Inter Ocean, September 2, 1886. | "Felt distinctly;" walls shook and furniture "shuffled about;" many sleepers startled from beds. |
| 37 | Sparland | Marshall | 41 02 | 89 27 | | S. to N. | | 10 | Miss Eva Erskine, school miss. | Deep, rumbling noise; "not sure" as to direction; light shock. |
| 38 | Springfield | Sangamon | 39 50 | 89 40 | | | | | Signal Service observer. | Not felt. |

*Report of earthquake observations, earthquake of August 31, 1886*—Continued.

**ILLINOIS—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | m. | s. | | |
| 39 | Sullivan | Moultrie | 39 38 | 88 39 | 2 | | | | B. F. Peaders, superintendent of schools. | Three-story brick building; oil in lamps "rushed from side to side; chandelier vibrated, etc.; two shocks very perceptible in upper stories." |
| 40 | Watseka | Iroquois | 40 47 | 87 46 | | | | | Henry Upsell. | "No motion perceptible that can be verified." |

**INDIANA.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration m. | Duration s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Blomingdale | Parke | 39 50 | 87 15 | | | | | R. C. Hobbs | Not felt. |
| 2 | Bloomington | Monroe | 39 11 | 86 33 | | | | | J. C. Branner | After learning of the earthquake from the newspapers a few thought they had felt it. No reliable reports. |
| | ......do | ....do | 39 11 | 86 33 | | | | | J. P. Maylor | After learning of the earthquake from the newspapers a few thought they had felt it. No relible reports. |
| 3 | Boonville | Warwick | 38 06 | 87 17 | 2 | | | 1 | R. D. Neller, county superintendent. | Noticed by few and not generally felt. |
| 4 | Brazil | Clay | 39 32 | 87 08 | 2 | | | | Chicago Inter Ocean | Distinctly felt on the streets and in second and third stories. Miners became alarmed and refused to work. |
| 5 | Brookville | Franklin | 39 26 | 84 59 | 1 | E. to W | 1 | | A. W. Butler | Shock distinctly felt; suspended objects swung E. and W.; especially noticeable in upper stories; not generally felt; no noise. |
| 6 | Butlerville | Jennings | 39 04 | 85 31 | | N. to S | | 2 | Signal Service observer. | Distinctly felt; no damage. |
| 7 | Centreville | Wayne | 39 51 | 84 59 | 1 | | | | J. H. Gentry | Felt an easy rocking sensation while lying down; the smoke bells over chandeliers swung considerably; people in upper stories of building considerably alarmed. |
| 8 | Connersville | Fayette | 39 40 | 85 08 | 2 | N. to S | | 25 | Signal Service observer. | Oscillations very distinct and continuous; direction indicated by motion of pictures, chair, and oil in lamp; some report two shocks and oscillations E. to W. |
| 9 | Covington | Fountain | 40 09 | 87 22 | | | | | J. Bingham | Not generally felt; some claim to have felt it. |
| 10 | Clinton | Vermillion | 39 40 | 87 26 | 1 | | | | C. Mathews | A person in bed felt shock and heard crockery rattle on mantel attached to chimney; in Parke County it was more severe. |

*Report of earthquake observations, earthquake of August 31, 1886*—Continued.

**INDIANA—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | *m.* | *s.* | | |
| 11 | Crawfordsville | Montgomery | 40 03 | 86 53 | | SE. to NW | | 30 to 60 | J. M. Coulter, professor, Wabash College. | Facts obtained from many persons; first shock a succession of short waves; chandeliers swung SE. to NW. |
| | ......do | ....do | 40 03 | 86 53 | | | | | E. C. Simpson, civil engineer. | On third floor narrow four-story brick building, chair moved, house rocked, wall paper and plastering cracked; short quick waves. |
| 12 | Danville | Hendricks | 39 47 | 86 31 | | | | | | Felt by many; in Masonic Block, third story, pictures swung from fastenings and windows rattled; clocks stopped and lamps swung to and fro 18 inches. |
| 13 | Engene | Vermillion | 39 59 | 87 28 | | | | | S. G. Vandyke | Not felt. |
| 14 | Evansville | Vanderburgh | 38 01 | 87 34 | 2 | | | 15 | Lonisville Post, September 1, 1886. | Shocks five minutes apart and rotary; houses rocked, and glassware thrown from shelves; stampedes in hotels and printing offices. |
| | ......do | ....do | 38 01 | 87 34 | 2 | | | 22 | Chicago Herald | Interval fifteen minutes; Ohio River fell a foot by Government gauge, and returned after five minutes. |
| | ......do | ....do | 38 01 | 87 34 | 1 | | | 10 | J. W. Compton | Distinct shock; chandeliers swayed and clock stopped; some felt dizziness and nausea. |
| | ......do | ....do | 38 01 | 87 34 | 4 | E. to W | 3 or 4 | | J. M. Gleason, insurance agent. | On fourth floor of hotel everything loose set in motion; doors, windows, and shutters rattled; furniture and pictures moved; people left house in alarm; distinctly undulatory. |
| 15 | Frankfort | Clinton | 40 18 | 86 31 | 2 | E. to W | | | W. S. Sims | Was in brick building facing S.; one side sank and rose, moving walls E. and W.; ran out into the street and felt so unbalanced I could hardly stand; bird-cages hung in a line running E. and W., and an inch or an inch and a half apart, clashed and rattled, commencing at the E. end; waves in rapid succession; alarm in the opera gallery; lamps swung E. and W.; no noise. |
| | ......do | ....do | 40 18 | 86 31 | | | | | M. Biorn | Panic at Opera House, where the electric light was set in violent motion E. and W.; no noise and no damage; not felt throughout the city. |
| 16 | Greencastle | Putnam | 39 40 | 86 52 | | | | | Signal Service observer. | Not felt; conditions for observation favorable. |
| 17 | Indianapolis | Marion | 39 48 | 86 10 | 1 | | | | Louisville Commercial, September 1, 1886. | Felt by a few in elevated buildings; no damage. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**INDIANA—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | *m.* | *s.* | | |
| | Indianapolis | Marion | 39 48 | 86 10 | 1 | | | 10 | Indianapolis Journal, September 1, 1886. | A shiver, without indications of direction. In the composing rooms the stands holding the cases swung several fractions of an inch; in the upper stories of the Dennison guests ran out in alarm, but it was not felt on the ground floors; a keystone fell from a second-story window; no one in the hotel knew of the shock; a lamp was shaken from a mantel, and the clock in the court-house tower was stopped; at the Signal Service office the first shock lasted eight seconds, the second six seconds, with an interval of a minute. |
| | ....do | ....do | 39 48 | 86 10 | 1 | | | 30 | Associated Press | Shock of a trembling or quivering character; alarm in Dennison Hotel, where a portion of the cornice was displaced; type cases shaken, and people prevented from writing at desks; the watchman fled from the court-house tower; people considerably frightened; not felt on ground floors. |
| 18 | Jasper | Dubois | 38 26 | 86 56 | 2 | N. to S. | | 10 | A. M. Sweeney | Horizontal undulatory movement; chandeliers swung five inches N. and S.; no noise. |
| | ..... do | ....do | 38 26 | 86 56 | 12 | | | | Louisville Post, September 1, 1886. | Windows and doors rattled; joists creaked; dishes thrown from shelves, and furniture swayed in upper rooms; tremors lasted an hour. |
| 19 | Kentland | Newton | 40 47 | 87 27 | | | | | W. H. Herhman, county superintendent. | Not felt. |
| 20 | Knightstown | Henry | 39 48 | 83 33 | | | | | Indianapolis Sentinel, September 2, 1886. | Felt very perceptibly; doors swayed and frame houses trembled; considerable consternation. |
| 21 | La Fayette | Tippecanoe | 40 36 | 86 53 | | | | | M. C. Stevens | Not felt. |
| 22 | La Porte | La Porte | 41 36 | 86 42 | 1 | W. to E. | | | Cincinnati Enquirer, September 1, 1886. | Severe; buildings rocked and doors rattled; suspended lamps and pictures swung; duration a number of seconds; no damage. |
| 23 | Lawrence County | | | | | | | | J. C. Bramer, Indiana University. | Not felt in the NE. corner of the county. |
| 24 | Liberty | Union | 39 39 | 84 26 | | E. to W. | | 35 | Cincinnati Enquirer, September 1, 1886. | Buildings swayed, and bric-a-brac shaken from walls; greatest consternation and fear. |
| 25 | Logansport | Cass | 40 46 | 86 22 | | | | | D. D. Fickle, county superintendent. | Not felt. |
| 26 | Madison | Jefferson | 38 46 | 85 24 | | | | | Louisville Post, September 1, 1886. | Buildings shaken; furniture jarred; doors and windows rattled. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**INDIANA—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | | | | |
| | Madison | Jefferson | 38 46 | 85 24 | | SSW. to NNE. | | 5 | J. H. Woolford | Felt rocking while in bed on first floor; chandeliers swung; doors rattled, and several walls cracked; people much disturbed, and some complained of nausea. |
| 27 | Michigan City | La Porte | 41 33 | 86 53 | 1 | N. to S. | | | Indianapolis Journal, September 2, 1886. | Severe, and felt principally on W. side of Franklin street; chandeliers swung, and tables and desks rocked; occupants of second and third stories were frightened to the streets. |
| 28 | Muncie | Delaware | 40 11 | 85 24 | | | | | J. F. Wildham | Not felt. |
| 29 | Nashville | Brown | 39 14 | 86 15 | | | | | Anonymous | Do. |
| 30 | Newcastle | Henry | 39 57 | 85 24 | 1 | E. to W | | 3 to 5 | W. M. Pence | On first floor, standing at desk writing; horizontal undulatory movement, possibly SE. to NW.; chandeliers swung E. to W. |
| 31 | New Cumberland | Grant | 40 23 | 85 30 | 1 | | | | J. Newbridge, Tornado Reporter. | Slight; no damage. |
| 32 | New Harmony | Posey | 38 10 | 87 55 | 3 | N. to S. | | 2 or 3 | F. D. Owen | First shock rattled windows, and gave the sensation of swaying; interval two or three seconds; second shock much harder, rattling windows and knick-knacks, and swaying furniture; chandelier, so hung it could hardly swing otherwise, swung N. to S. 1 foot; floor rose and fell, causing nervousness and nausea; third shock lighter; toward morning awakened by bed swaying N. to S. |
| 32 | New Harmony | Posey | 38 10 | 87 55 | 1 | | | 3 or 4 | Prof. R. Owen | An invalid in bed, second story, brick house, felt vertical motion; a few seconds later she felt a similar motion. A decided shock; swinging lamps; no noise. |
| | do | do | 38 10 | 87 55 | 2 | E. to W. | | | H. P. Owen | Stood facing south, reading; felt body swayed from E. to W. for a few seconds, and again ten or fifteen seconds later. |
| | do | do | 38 10 | 87 55 | | E. to W. | | | C. S. Lichtenberger | Hanging lamp and wooden pole for display of goods swung E. to W. |
| 33 | Noblesville | Hamilton | 40 03 | 86 01 | 2 | | | | Indianapolis Journal, September 1, 1886. | First shock very generally felt; second moved lamps and loose objects on tables and shelves. |
| 34 | North Manchester | Wabash | 41 00 | 85 46 | 1 | | | | Cincinnati Commercial Gazette, September 3, 1886. | Distinctly felt; affrighted people left their beds. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**INDIANA—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | *m.* | *s.* | | |
| | North Manchester | Wabash | 41 00 | 85 46 | 2 | N. to S. | | 3 or 4 | A. Miller, dentist. | In bed in second story, brick house; felt strong undulating; lamps swung apparently E. to W.; direction generally thought to be E. to W.; duration, three or four seconds each; second shock E. to W. |
| 35 | Portland | Jay | 40 27 | 84 58 | | | | | Cincinnati Enquirer, September 1, 1886. | Felt by many; farmers awakened in adjoining county. |
| 36 | Princeton | Gibson | 38 24 | 87 33 | 1 | | | | H. L. Wallace | Slightly felt by many; in second stories felt as an undulation; pendent objects swung and sleepers awakened. |
| 37 | Rensselaer | Jasper | 40 57 | 87 08 | | | | | R. M. Nelson, county superintendent. | Hardly felt; a party 20 miles NW. of town recognized it as an earthquake. |
| 38 | Rising Sun | Ohio | 38 52 | 84 50 | 1 | E. to W. | | 30 | Cincinnati Enquirer, September 1, 1886. | Violent shock; three waves; pictures rattled, ornaments thrown down, plastering dislodged, and glass broken; many awakened. |
| | do | do | 38 52 | 84 50 | | | | | Cincinnati Times-Star, September 1, 1886. | Generally felt; wharf boat rocked, and the strongest doors and windows rattled like loose lumber; many rushed from their houses. |
| 39 | Rockville | Parke | 39 47 | 87 14 | | S. to N. | | | J. F. Campbell, county surveyor. | In second story new stone court-house, writing; felt dizzy; book weight swung N. and S., and people in upper stories were badly frightened; noticed by few on ground floor. |
| | do | do | 39 47 | 87 14 | 1 | S. to N. | | 6 | Cincinnati Enquirer, September 1, 1886. | Forcibly felt, with two vibrations per second; buildings trembled and chandeliers swung; guests in hotel terribly shaken. |
| 40 | Salem | Washington | 38 38 | 86 07 | | | | | J. D. Alvis, postmaster | Not felt in our section. |
| 41 | Shelbyville | Shelby | 39 32 | 85 47 | | | | | R. W. Harrison | Not felt. |
| 42 | South Bend | Saint Joseph | 41 44 | 86 14 | | E. to W. | | | J. G. Dooland | Clocks stopped; pictures moved from wall, and oil in lamp oscillated one-quarter of an inch; house tipped E. and W. repeatedly on third floor of building; not generally felt on ground floor. |
| 43 | Spencer | Owen | 39 19 | 86 47 | 2 | N. to S. | | | Indianapolis Sentinel, September 2, 1886. | Shocks very severe and distinct; chandeliers vibrated, windows rattled, and rocking-chairs rocked quite violently; considerable fright at the Opera House. |
| 44 | Terre Haute | Vigo | 39 29 | 87 24 | 2 | | | 40 | Associated Press | Plastering dislodged and sleepers awakened by swaying beds and rattling windows; many rushed to the streets and some were nauseated; panic among a large audience at the Opera House; severely felt over the entire city; no rumbling; interval ten seconds. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**INDIANA—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | | | | |
| | Terre Haute | Vigo | 39 29 | 87 24 | | | | | L. P. Alden | Not noticed by a majority. In Rose Orphan Home five out of eighty persons felt it slightly. Swaying in upper galleries of Opera House caused a panic, which was easily controlled by police; felt by some on ground floor. |
| | do | do | 39 29 | 87 24 | | | | | Miss M. Straus | House swayed E. and W.; pendent objects swung considerably; felt dizziness. |
| 45 | Union City | Randolph | 40 13 | 84 48 | 2 | S. to N. | | | Indianapolis Journal, September 2, 1886. | Public opinion regarding an earthquake divided until learning of it elsewhere; the first waving disturbed furniture and movable objects; the second clicked shutters and lasted thirty seconds; decidedly undulatory; interval thirty seconds. |
| 46 | Valparaiso | Porter | 41 28 | 87 03 | 1 | | | | Associated Press | Plainly felt; buildings rocked, windows cracked, and pictures thrown from walls; there was a general rush from buildings to the street. |
| | do | do | 41 28 | 87 03 | | | | | F. Greenaw | A slight tremor, then a rocking, causing some to feel dizzy and nauseated; chandeliers swung, pictures moved from wall, and in Merchants' Hotel plastering was thrown down; people rushed from upper stories; felt by some on the streets. |
| 47 | Vevay | Switzerland | 38 46 | 85 03 | 3 | NE. to SW. | | | C. G. Boerner, Signal Service observer. | Direction obtained from many good observations; with maximum intensity, deep rumblings, jarring of windows, increasing to swaying, causing unsteadiness to those standing; houses shook and people rushed to the streets; most severe in upper stories; second less severe, and third faint. |
| 48 | Wabash | Wabash | 40 49 | 85 49 | | | | | Cincinnati Commercial Gazette, September 3, 1886. | Not felt. |
| 49 | Warsaw | Switzerland | 38 48 | 84 54 | | | | | W. H. Boreri, postmaster. | Not felt. |
| 50 | Washington | Warren | 40 17 | 87 17 | 2 | | | 1 or 2 | C. P. Brown | A jar; noticed by few. |
| 51 | Worthington | Greene | 39 09 | 86 58 | 2 | E. to W. | | | Indianapolis Sentinel, September 2, 1886. | Plainly felt; many sleepers awakened. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**IOWA.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | *m.* | *s.* | | |
| 1 | Belle Plaine | Benton | 41 54 | 92 17 | | | | | Prof. S. Calvin, Iowa State University. | Notes on "Big Well," from letter to Professor McGee. Was commenced August 24; water reached 26, and next day flow was beyond control; coincidence in time with Charleston shock wholly accidental; these wells reach only to a stratum of sand and gravel below blue clay; Big Well reaches it at depth of 190 feet; the others, on higher ground, are deeper, the deepest 300 feet; the blue clay is over 100 feet thick; water in sand and gravel beneath is under pressure which is resisted by the impervious layer of clay; when Big Well commenced others diminished; itself has gradually diminished. |
| 2 | Burlington | Des Moines | 40 50 | 91 05 | 1 | | | | Associated Press | A slight shock; some in high buildings rushed to the street. |
| | do | do | 40 50 | 91 05 | 1 | N. to S. | | 5 | Charles Wachsmuth | Shock distinctly felt, especially in upper stories; noticed by a very large number, and its nature recognized. |
| 3 | Cedar Rapids | Linn | 41 58 | 91 39 | | | | | Signal Service observer. | Sudden and violent agitation of mercury in barometer; oscillations from 30.12 to 30.27 inches; barometer jumped from 30.16 to 30.14, rose to 30.30, stopped at 30.20, and oscillated slightly. |
| 4 | Charles City | Floyd | 43 04 | 92 40 | | | | | Prof S. Calvin, etc. | Not felt. |
| 5 | Corydon | Wayne | 40 45 | 93 19 | | | | | J. S. Whittaker, postmaster. | Not felt within 100 miles. |
| 6 | Davenport | Scott | 41 31 | 90 34 | 1 | | | | Associated Press, September 1, 1886. | At Soldiers' Home, 3 miles N. of city, the warden reports "shock passed through buildings;" they shook quite perceptibly, and inmates were considerably frightened. |
| | do | do | 41 31 | 90 34 | | E. to W. | | 1 or 2 | H. L. Tiffany | One-half mile NE. of city superintendent of Orphans' Home felt it; chandeliers vibrating and glass pendants striking the metal. |
| 7 | Des Moines | Polk | 41 35 | 93 36 | | | | | Chicago Herald, September 2, 1886. | Felt slightly in high buildings. |
| | do | do | 41 35 | 93 36 | | | | | J. E. Hendricks | "Rumors," but no positive evidence. |
| | do | do | 41 31 | 93 36 | | | | | William H. Merritt, postmaster. | Not felt. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**IOWA—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | *m.* | *s.* | | |
| 8 | Dubuque | Dubuque | 42 29 | 90 39 | 2 | | | | Associated Press | Tops of high buildings felt to vibrate violently; printers in fourth story Herald building rushed to the ground; much fright in Opera House, and many left building; first wave lasted ten seconds; second six seconds; guests fled from upper rooms of hotels. |
| | do | do | 42 29 | 90 39 | 1 | | | 3 | New York World and New York Times, September 1, 1886 | "Slight earthquake;" tall buildings left by occupants, and audience in Opera House left seats. |
| | do | do | 42 29 | 90 39 | 3 | | | 25 | Dubuque Daily Herald, September 1, 1886. | Felt in upper stories of tall buildings in many places; nausea experienced in several; duratiou twenty-five seconds, according to most authentic sonrces; first tremor lasted eight or ten seconds; second the same; third a little less; it was thought to be a powder explosion; everybody had a very vague idea of what had happened; large audience iu Opera House; seats shook and some rattled; those standing against walls thought them falliug, and ran ont; thirty or forty left building; printers felt Herald building sway; some clerks in plow factory left building. |
| 8 | Dubuque | Dubuque | 42 29 | 90 39 | | | | | Dubuque Daily Herald, September 1, 1886. | In one house baby carriage moved and pictures violently shaken. In the Julian guests left rooms half-dressed and some women screamed; at some other houses no oue noticed shock. |
| | do | do | 42 29 | 90 39 | | | | | Dubuque Daily Herald, September 2, 1886. | Drawbridge was open; structure trembled; draw oscillated like a man was ou each end producing the movement. Hundreds of people had singular sensations, which at the time were unaccountable. |
| | do | do | 42 29 | 90 39 | | N. to S. | | 30 | Miss E. L. Hunt, general mauager telegraph company, through Dr. A. Horr. | With five other ladies in two-story brick block; chair moved, then the house; chandelier swung and bell ou spiral spring rang; "earthquake" was mentioned, and all rushed into the street; undulatory, and continuous for half minute; motion N. to S., as shown by swaying of people. In letter of February 25, Dr. Horr states: Ladies repeated actions and found lapsed time from feeling of shock till striking of clock two and a half minutes. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**IOWA—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | m. | s. | | |
| | Dubuque | Dubuque | 42 29 | 90 39 | 1 | | | 2 | | Third story, Dubuque Herald office, near E. end of building on sandy soil. Not over two seconds' duration; no noise; felt one shock, some say two. Hanging lamps swayed slightly; lamps in brackets trembled. Floor seemed to move suddenly to the north. Felt dizzy; knees weak. Parties standing near north windows say the walls seemed to sway out and in. Building a large three-story and basement brick, detached from other buildings. Felt more severe than elsewhere in city. |
| 9 | Forest City | Winnebago | 43 15 | 93 38 | | | | | M. Cooper, postmaster. | No mention made of shock by town people. Was lying quietly in bed, and heard rumbling like a dray on pavement repeated three times within five or ten minutes. |
| 10 | Fort Madison | Lee | 40 37 | 91 18 | | | | | J. M. T. Myers | Not felt. |
| 11 | Hopkinton | Delaware | 42 20 | 91 14 | | | | | A. G. Wilson, Lenox College. | Felt by only two. Shaking lasted several seconds; windows and doors vibrated. |
| 12 | Independence | Buchanan | 42 28 | 91 54 | | | | | D. Darman, postmaster | Not felt. |
| 13 | Indianola | Warren | 41 22 | 93 33 | | | | | G. C. Carpenter | Do. |
| 14 | Iowa City | Johnson | 41 38 | 91 32 | | | | | S. Calvin | Gives observations of others. A few felt two distinct shocks. Several quite certain that they perceived the earthquake. |
| | ......do | ....do | 41 38 | 91 32 | | | | | F. E. Nipher, of Washington University, St. Louis. | Gives observations of others. Man in third story leaning back in chair was thrown forward; heard of several who recognized it; in several houses stove ware heard to rattle. |
| 15 | Keokuk | Lee | 40 23 | 91 22 | | | | | Weekly Gate City, Keokuk, September 2, 1886. | A gentle undulation; nothing said about shock in the evening, but next morning a number said they had felt a peculiar sensation and thought it an earthquake; not felt on streets or first floor; two parties noticed shock, and building vibrated for a minute; in one room window-blinds oscillated, and occupants made dizzy; three others also felt shock. |
| | ......do | ....do | 40 23 | 91 22 | | | | | C. P. Birge | Felt by few persons. |
| 16 | Manchester | Delaware | 42 27 | 91 27 | | | | | A. G. Wilson, Lenox College. | Shock felt. |
| 17 | Maquoketa | Jackson | 42 03 | 90 40 | | | | | F. W. Crane, postmaster. | Not felt. |
| 18 | Marshalltown | Marshall | 42 02 | 92 55 | | | | | D. Arnold | Do. |

*Report of earthquake observations, earthquake of August 31, 1886*—Continued.

**IOWA—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | | | | |
| 19 | Monticello | Jones | 42 12 | 91 11 | | | | | A. G. Wilson, Lenox College. | Shock felt. |
| 20 | Ottumwa | Wapello | 41 01 | 92 24 | | | | | G. B. Evans, postmaster. | Not felt. |
| 21 | Waverly | Bremer | 42 43 | 92 28 | | | | | A. Shepherd, postmaster. | Do. |
| 22 | Webster City | Hamilton | 42 28 | 93 50 | | | | | C. Aldrich | Do. |
| 23 | Washington | Washington | 41 17 | 91 42 | | | | | (?) postmaster. | Do. |

**KENTUCKY.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Ashland | Boyd | 38 14 | 82 37 | | | | | Louisville Commercial. | Town shook fearfully; several houses thrown down, and three or four persons injured. |
| 2 | Bagdad | Shelby | 38 30 | 85 07 | 1 | | | | E. P. Denton | Lower floor, frame depot; not severe enough to shake furniture; felt a kind of unconsciousness; very light; hardly noticed till next day; some wells went dry; soil, clay; heavy rock 10 feet down. |
| 3 | Bardstown | Nelson | 37 49 | 85 29 | | | | | Anonymous | |
| 4 | Beattyville | Lee | 37 39 | 83 47 | 2 | W. to E | 1 | | H. Tucker | Heavy rolling noise accompanied it; second very light; suspended objects swung, doors rattled, frame houses creaked. In two-story frame house, on lounge; saw and felt lounge rock; a gentle swaying from W. to E. |
| 5 | Belleview | Christian | 38 21 | 85 10 | | | | | Cincinnati Times-Star, September 1, 1886. | Consternation in three-story opera house; numbers stampeded; not felt on ground; every window rattled and houses creaked; decidedly undulatory. |
| 6 | Booneville | Owsley | 37 33 | 83 44 | | | | | No name | Most people felt it distinctly and recognized it as an earthquake; some affected with seasickness; some did not feel it. |
| 7 | Bowling Green | Warren | 36 59 | 86 25 | 1 | | | | J. E. Younglove | Very light; no noise; more noticeable in adjoining localities. |
| 8 | Brownsvllle | Edmonson | 37 11 | 86 12 | 2 | | | 30 | W. Compton | Some felt rocking, causing nausea; not felt by every one. |
| 9 | Burkesville | Cumberland | 36 49 | 85 23 | 3 | E. to W | | | A. J. Marshall | Houses shook considerably; furniture moved and small objects disturbed; considerable excitement; undulatory. |

*Report of earthquake observations, earthquake of August 31, 1886*—Continued.

**KENTUCKY—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | m. | s. | | |
| 10 | Campton | Wolfe | 37 50 | 83 36 | 3 | N. W. to S. E. | 3 | | E. B. Collis | Strongly felt; doors and windows shook violently suspended objects swung, and houses swayed; animals alarmed. |
| 11 | Caseyville | Union | 37 31 | 88 03 | | | | | Louisville Courier-Journal, September 4, 1886. | Sleepers awakened by shaking of beds, rocking of houses, and trembling of bric-a-brac; shocks frequent, and lasted perhaps ten minutes; no damage. |
| 12 | Catawba | Pendleton | 38 41 | 84 19 | | | 1 | 30 | M. C. Shaw | Noticed by few who recognized it; slight rocking. |
| 13 | Catlettsburg | Boyd | 38 24 | 82,36 | | | | | Louisville Commercial, September 1, 1886. | Goods shaken from shelves, and doors and windows rattled; people ran out of houses; much excitement. |
| 14 | Central City | Muhlenberg | | | | | | 10 | Louisville Post, September 1, 1886. | Quite severe; windows rattled quite violently. |
| 15 | Clinton | Hickman | 36 40 | 88 58 | | | | | W. C. Porter, postmaster. | Undulatory motion noticed by an entire congregation; suspended objects shook most perceptibly; some bricks fell from chimneys and chandelier swung 2 inches; soil, clayey loam; no noise. |
| 16 | Columbia | Adair | 37 07 | 85 19 | 3 | NW | 2 to 3 | | A. N. Thompson | Rolling felt by many; windows clattered and movable objects shook; some excitement. |
| 17 | Covington | Kenton | 39 05 | 84 32 | | | | | I. J. Evans, watchmaker. | |
| 18 | Cynthiana | Harrison | 38 23 | 84 16 | 2 | N. to S. | 2 or , | | S. W. Chapman | Undulatory, with tremors; lamps swung 6 inches N. to S. |
| 19 | Dayton | Campbell | 39 04 | 84 29 | | | | | Cincinnatti Times-Star, September 1, 1886. | Houses shook considerably and many inmates ran out; hanging lamps swung; not felt on sidewalk. |
| | do | do | 39 04 | 84 29 | 1 | N. to S. | | | F. J. Sutton, attorney. | In bed, ground floor; vertical swaying of bed, followed by horizontal swaying; door shut with some force. |
| 20 | Eastpoint | Floyd | 37 50 | 82 59 | | N. to S. | 4 or 5 | | H. L. Carter | Two or three heavy shocks, first the strongest; houses shook violently, lamp overturned; people frightened; clock stopped. |
| 21 | Edmonton | Metcalf | 36 59 | 85 39 | 2 | | 2 | | C. Wightman | Well-marked shocks; houses shook violently, doors, windows, and light objects rattled; quick undulations. |
| 22 | Elizabethtown | Hardin | 37 41 | 85 52 | 1 | | | | A. Chester | Felt by some; noticed mostly as a sinking sensation; a few lamps swung; no noise. |
| 23 | Frankfort | Franklin | 38 12 | 84 53 | | | | 12 | Louisville Courier-Journal, September 2, 1886. | Distinctly felt and recognized; in some parts of city two, in others three shocks or vibratory motions. Windows rattled, beds and tables shook, and chandeliers swung. Duration about twelve seconds. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**KENTUCKY—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
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| | | | ° ′ | ° ′ | | | m. | s. | | |
| 24 | Glasgow | Barren | 85 53 | 36 59 | | | | | Louisville Courier-Journal, September 2, 1886. | Felt by many; very sensibly felt in upper stories; doors and windows rattled on ground floors. |
| | ......do | ....do | 85 53 | 36 59 | 2 | | 1 | | M. R. Colton | Noticed by many, first well marked; houses swayed; windows rattled; suspended objects moved. |
| 25 | Grayson | Carter | 38 21 | 82 57 | 2 or 3 | | 3 | | F. T. Eddy | Generally felt as a strong vibration and unsteadiness, some say accompanied by rumbling; houses rocked. |
| 26 | Greensburgh | Green | 37 16 | 85 32 | 2 | NW | 1 or 2 | | U. S. Franklin | Felt by many; rattling of windows; unsteady motion of houses; some excitement. |
| 27 | Harlan | Harlan | 36 57 | 83 19 | 1 | | | | A. Marlow | Not generally felt, though some felt it distinctly; felt most in upper rooms. |
| | ......do | ....do | 36 57 | 83 19 | 2 or 3 | | | | A. D. Smith | Generally felt throughout county, and at many points felt strongly; plastering shaken down; furniture moved; chimneys cracked in one or two houses. |
| 28 | Harrodsburgh | Mercer | 37 46 | 84 53 | 2 | SE | 1 | | S. H. Lee | Well-marked shocks, first strongest; shaking houses very perceptibly; some excitement. |
| 29 | Hazard | Perry | 37 21 | 83 15 | 3 | N. to S. | 2 or 3 | | T. R. Wilson | First most violent; light objects thrown down; plastering cracked; bricks thrown from chimneys; houses swayed and cracked, and people ran out. |
| 30 | Hodginsville | La Rue | 37 32 | 85 48 | | | | | W. A. Spackman | Well-marked shock. |
| 31 | Hyattsville | Garrard | 37 36 | 84 33 | 2 | | 2 | | G. H. Pendry | Felt by many as a sinking sensation; doors and windows rattled; houses cracked and groaned. |
| 32 | Lawrenceburgh | Anderson | 38 02 | 84 55 | 1 | | | | J. Newhall | Loose objects rattled; undulatory, especially in upper stories. |
| 33 | Lebanon | Marion | 37 34 | 85 17 | 2 | SE. to NW | | 4 to 5 | W. W. Wathen, postmaster. | Interval two or three seconds; not generally felt; noticed by some, especially in upper stories. |
| 34 | Leitchfield | Grayson | 37 30 | 86 19 | 1 | | | 20 | J. R. Barton, postmaster. | Light, felt by majority; no noise; sitting reading second story; horizontal undulation. |
| 35 | Lexington | Fayette | 38 02 | 84 32 | | | | 15 | Associated Press | Slight shock. |
| | ......do | ....do | 39 02 | 84 32 | | | | 15 | Louisville Commercial, September 1, 1886. | Very perceptible. In a suburb, windows and doors creaked and buildings trembled. |
| 36 | London | Laurel | 37 10 | 84 9 | 2 | | | | R. M. Jackson, postmaster. | Light; shock felt distinctly. Sitting upstairs reading. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**KENTUCKY—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | | | | |
| 37 | Louisville | Jefferson | 38 15 | 85 45 | | N. to S. | | 30 | Associated Press | Felt throughout the city; high buildings rocked violently and inmates rushed to the streets. Several public meetings were broken up, and at Masonic Temple a wild panic occurred and the audience made a stampede for the exits; furniture moved and windows and lamps broken in various hotels; great excitement; no serious damage. |
| | do | do | 38 15 | 85 45 | 4 | | | 4 | Louisville Post, September 1, 1886. | Felt on ground floors; many ran from houses; a number nauseated. Felt throughout the city, but no damage; direction S. to easterly. |
| | do | do | 38 15 | 85 45 | | | | | Louisville Commercial, September 1, 1886. | Generally felt throughout city, especially in high buildings; most noticeable on Main, Market, Jefferson, and Green streets between First and Sixth streets; some left houses in alarm; no damage, but audiences in theaters alarmed. Compositors on fifth floor Commercial left cases and hesitated to return. At a meeting in Masonic Temple the galleries were hurriedly vacated and a wild panic ensued. Throughout the city light articles in many instances overthrown and broken. The shock was lighest in the eastern parts of city. |
| | do | do | 38 15 | 85 45 | | | | | do | A telegram announcing earthquake at Louisville reached Cleveland a moment before shock. |
| | do | do | 38 15 | 85 45 | 3 | | | | E. Adams | Quite severe. |
| | do | do | 38 15 | 85 45 | 3 | | | | J. Bryson | Three distinct shocks; felt most in city proper, which is on sand and gravel beds 100 feet deep. |
| | do | do | 38 15 | 85 45 | 2 | S. to N. | | | R. T. Holey | No noise; in rocking-chair on first floor of house, on terrace 10 or 12 feet above general level, chair rocked perceptibly; stronger in upper floors. |
| 37 | do | do | 38 15 | 85 45 | | N. to S. | | 15 or 20 | J. Howard | Leaning back in revolving chair, two-story brick house; waving motion of chair followed by horizontal undulation of house; pronounced rattling of shutters, which indicated the direction; not noticed on first floor; sandy soil. |
| | do | do | 38 15 | 85 45 | | | | | R. C. B. Thurston | Duration first shock, twenty-five or thirty seconds; cessation of tremors in one minute and forty seconds. In second story, half-story brick house, quite severe; shutters, windows, and doors rattled considerably; servant awakened; people nauseated. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**KENTUCKY—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | m. | s. | | |
| 38 | Manchester | Clay | 37 14 | 83 47 | 1 | | 2 | | C. B. Lyttle, postmaster. | Windows rattled; hilly or mountainous country. |
| 39 | Mannington | Christian | 39 04 | 84 30 | | | | 45 to 60 | J. H. Allen, superintendent coal company. | |
| | do | do | 39 04 | 84 30 | | | 1 | | Signal Service observer. | Light; duration about one minute. |
| 40 | Marion | Crittenden | 37 20 | 88 03 | | | | | R. C. Walker, postmaster. | Very light; noticed by few. |
| 41 | Maysville | Mason | 38 40 | 83 45 | | | | | Cincinnati Enquirer, September 1, 1886. | Stampede of inmates of houses; windows rattled; swaying of floors, furniture, and walls plainly noticeable; duration, several seconds. |
| | do | do | 38 40 | 83 45 | | | | | Louisville Courier-Journal, September 2, 1886. | Very distinctly felt; window shutters and panes rattled; buildings swayed gently; people left buildings; duration several minutes. |
| 42 | Midway | Woodford | 38 08 | 84 41 | 2 | NW. to SE | | | T. Tenny | Two distinct shocks; felt very strongly by those in bed. |
| 43 | Morehead | Rowan | 38 13 | 83 30 | 2 or 3 | N. to S | 1 | 30 | G. Campbell | Quite forcible; generally felt; rattling of everything loose; strong swaying of houses; some persons nauseated. |
| 44 | Mount Savage | Carter | 38 17 | 82 56 | 4 | | | | T. L. Bosworth | In second story, on bed, which shook violently, as did the house and everything in it; duration from beginning of first to beginning of second, half minute. |
| 45 | Mount Sterling | Montgomery | 38 03 | 84 00 | | | | | do | |
| 46 | Newport | Campbell | 39 06 | 84 30 | 1 | NW. to SE | | 35 | J. Brookshaw | "My two-story frame house began to vibrate." |
| | do | do | 39 06 | 83 30 | | | | | Cincinnati Times-Star, September 1, 1886. | "Stones in street for several feet loosened and raised several inches." |
| 47 | Nicholasville | Jessamine | 37 52 | 84 56 | 2 | NW | 1 | | A. N. Castle | Generally felt; vibratory; trembling of objects and some houses. |
| 48 | Owensborough | Daviess | 37 44 | 87 05 | 2 | | 2 | | Louisville Post, September 1, 1886. | Distinctly felt all over city; two-story houses rocked, and many ran into the streets. |
| 49 | Owenton | Owen | 38 32 | 84 52 | 3 | | 1 | | J. R. Manning | No noise. |
| 50 | Paducah | McCracken | 37 04 | 88 36 | | | | | Louisville Post, September 1, 1886, | Very distinct in some portions of city; hardly perceptible in others. Doors rattled and chairs moved; panic at opera-house; people rushed out pell-mell; duration several seconds; a very distinct sound of a falling wall. |
| | do | do | 37 04 | 88 36 | | | | | J. R. Cobourn, manager Western Union Telegraph Co. | Was at home; neither myself nor wife noticed it; a neighbor did, and spoke of it; night operator, four squares off felt it, very sensibly. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**KENTUCKY—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | *m.* | *s.* | | |
| 51 | Pikesville | Pike | 37 36 | 82 33 | 4 | | 3 | | J. E. Stewart, attorney | First shock, SE. to NW.; twenty minutes later second shock, E. to W.; in a few moments third shock, E. to W., and less severe; fourth very light; bed shook; windows rattled; apparent swaying and settling of house. |
| 52 | Pineville | Bell | 36 46 | 83 41 | 3 | NW | 2 or 3 | | J. F. Hunnston | Violent shaking of houses; glass broken; objects overturned and people alarmed; generally felt throughout county; undulatory. |
| 53 | Prestonburgh | Floyd | 37 46 | 82 48 | 2 or 3 | SE | 2 or 3 | | C. S. Moffat | Some frightened; undulatory; end of houses rising and falling suddenly with considerable force. |
| 54 | Richmond | Madison | 37 44 | 84 19 | 2 | | | | C. H. Tullock | Duration several minutes. |
| 55 | Sand Spring | Jackson | 37 32 | 84 05 | 2 | | 2 | | R. Galloway | Houses shaken and windows rattled; undulatory. |
| 56 | Sandy Hook | Elliott | 38 10 | 83 12 | 2 | | | | J. C. Clark | Felt very strongly by everybody in county, but no special damage; ground heaved in short waves; plastering fell in one or two houses. |
| 57 | Scottsville | Allen | 36 45 | 86 08 | 2 | E. to W | 1 | | B. Smallwood | Houses much shaken and some people frightened; crockery shaken off shelves; suspended objects swung violently. |
| 58 | Somerset | Pulaski | 37 05 | 84 39 | 2 or 3 | NW. to SE | 1 | | C. B. Norton | Felt by most people; strong in upper stories; windows and crockery rattled; undulatory motion; some alarm. |
| | ......do | ....do | 37 05 | 84 39 | 3 | | | | Louisville Commercial, September 2, 1886. | All buildings more or less shaken; inmates ran out of some. In one or two places light articles were shaken off mantels; seco d and third lighter than first. |
| | ......do | ....do | 37 05 | 84 39 | | W. to E | 1 | 30 | T. Whinery, civil engineer. | Several shocks, first heaviest; others light tremors. |
| | ......do | ....do | 37 05 | 84 39 | | | | | S. Whinery | First shock jarred house perceptibly; mirror over bureau struck against wall; no damage; noticed by about half the people. |
| 59 | Stanford | Lincoln | 37 32 | 84 39 | 2 | | 2 or 3 | | A. W. Bowles | Strong shocks; houses shook and some plastering thrown down; hanging lamps swung 6 inches; very generally felt; much excitement. |
| 60 | Whitesburgh | Letcher | 37 14 | 82 56 | 3 or 4 | NW | 2 | | M. B. Parrish | Very strong, especially the first; crockery fell, some glass cracked, and houses swayed and groaned. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**LOUISIANA.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | | | | |
| 1 | Alexandria | Rapides | 31 18 | 92 22 | | | | | E. T. Merrick | Not felt. |
| 2 | Bayou Sara | West Feliciana. | 30 44 | 91 19 | | | | | F. M. Munford, postmaster. | Do. |
| 3 | Covington | St. Tammany | 30 28 | 90 03 | | | | | C. Heutz, postmaster | Do. |
| 4 | Franklinton | Washington | 30 48 | 90 08 | | | | | T. M. Babington, postmaster. | Do. |
| 5 | Natchitoches | Natchitoches | 31 41 | 93 02 | | | | | E. T. Merrick | Do. |
| 6 | Merrick Post-office | Pointe Coupée | | | | | | | do | Do. |
| 7 | New Orleans | Orleans | 29 58 | 90 07 | | | | | New Orleans Picayune, September 2, 1886. | |
| | do | do | 29 58 | 90 07 | | | | | J. Albrecht, M. D | Not felt. |
| | do | do | 29 58 | 90 07 | | | | | New York Sun, September 2, 1886. | Three or four persons felt shock. |
| 8 | Port Vincent | Livingston | 30 21 | 90 50 | | | | | D. C. Leftwich, postmaster. | Not felt. |
| 9 | Rigolets Light-house | | | | | | | | Picayune, September 5, 1886. | |
| 10 | Shreveport | Caddo | 32 29 | 93 41 | | | | | E. T. Merrick | Not felt. |
| 11 | Winnsborough | Franklin | 32 07 | 91 40 | | | | | S. Wylie, postmaster | Do. |

**MAINE.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Augusta | Kennebec | 44 18 | 69 45 | | | | | W. M. D | Not felt. |
| 2 | Bar Harbor | Hancock | 44 25 | 68 10 | | | | | do | Do. |
| 3 | Bethel | Oxford | 44 24 | 70 46 | | | | | | Do. |
| 4 | Brighton | Cumberland | 45 02 | 69 41 | | | | | | Do. |
| 5 | Ferry Village | do | | | | | | | Luther Farrar | Do. |
| 6 | Gardiner | Kennebec | 44 12 | 69 45 | | | | | W. M. D | Do. |
| 7 | Kent's Hill | do | 44 23 | 69 57 | | | | | do | Do. |
| 8 | Mayfield | Somerset | 45 08 | 69 56 | 1 | | 1 | | do | Slight. |
| 9 | Orono | Penobscot | 44 53 | 68 41 | | | | | do | Not felt. |
| 10 | Portland | Cumberland | 43 41 | 70 14 | | | | | do | Do. |
| 11 | Riverside | Kennebec | 44 24 | 69 41 | | | | | do | Do. |
| 12 | Sanford | York | 43 24 | 70 45 | | | | | do | Do. |
| 13 | Windsor | Kennebec | 44 18 | 69 35 | | | | | do | Do. |
| 14 | Woolwich | Sagadahoc | 43 56 | 69 48 | | | | | do | Do. |

*Report of earthquake observations, earthquake of August 31, 1886*—Continued.

**MARYLAND.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | *m.* | *s.* | | |
| 1 | Annapolis | Anne Arundel | 38 58 | 76 32 | | | | | New York Herald, September 1, 1886. | Felt by some quite sensibly; some occupying chairs felt them move; not felt on the streets; felt more or less in all sections of the city. |
| 2 | Baltimore | Baltimore | 39 20 | 76 37 | | | | 30 | Associated Press | More perceptible in NE. and NW. part of city; at the American office it was quite perceptible, moving printers' cases 6 inches. |
| | do | do | 39 20 | 76 37 | 3 | S. to N | | | New York Tribune, September 1, 1886. | Lasted several seconds; plainly felt in upper portion American building; on sixth floor printers' cases moved 5 or 6 inches; employés much frightened; building, chairs, and desks swayed; more perceptible in higher and western parts of city. |
| | do | do | 39 20 | 76 37 | 2 | W. to E | | | Mrs. M. M. Piggot | Sewing-machines on rollers in third story moved several inches, then back again; tassels and ornaments quivered; recognized as an earthquake; house on very high ground. |
| | do | do | 39 20 | 76 37 | 2 | SE. to NW | | | P. M. Reese | Duration first shock, twenty or thirty seconds; second shock, several seconds; intensity light; second shock lightest. In third story, brick building, 150 feet, above tide-water. Ground, clear sand to great depth. Went down-stairs when we felt shock. |
| | do | do | 39 20 | 76 37 | | | | | H. C. Wagner | Not felt at 227 Eutaw street. |
| | do | do | | | | | | | G. W. C. Krebs | Reading on second floor; door rattled; chandelier swung violently; felt nausea. |
| | do | do | 39 20 | 76 37 | | W. to E | | 45 | R. Randolph, civil engineer. | |
| | do | do | 39 20 | 76 37 | | | 1 | | Signal Service observer. | "Distinct shock." |
| 3 | Leading Point Light-house. | do | 39 20 | 76 37 | 2 | SW. to NE | | | William Glenn, Baltimore Sun, September 11. | Pendulums swinging in planes at right angles; the one swinging N. to S. stopped; E. to W. one did not. |
| 4 | Bishop's Head | Dorchester | 38 18 | 76 03 | 2 | | | | Z. Harper, keeper light | Generally felt; rattled weights in window. |
| 5 | Blakiston's Island Light-house. | | | | 1 | | | | S. L. Phillips | Facts obtained from keeper light-house: Mr. P. was in house near light-house; shock moderate; three undulations of house; door swung. |
| 6 | Cambridge | Dorchester | 38 35 | 76 06 | 1 | SW. to NE | | 5 | J. L. Bryan, school commissioner. | No noise; not generally felt, but noticed decidedly by some; child awakened; pieces of plaster fell from chimney, etc.; facts obtained from good observers. |
| 7 | Cove Point Light-house. | | | | | | | | H. Dehl, keeper | Light tremor; noticed by only one person. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**MARYLAND—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | m. | s. | | |
| 8 | Fish Commission Station. | | 39 33 | 76 07 | | E. to W. | | | W. P. Saurhoff | Clock stopped; house trembled and rocked, bed shook violently. |
| 9 | Frederick | Frederick | 39 25 | 77 24 | 2 | | | | E. D. Shriner | Three miles NE. of Frederick; sitting on sofa, which swayed and trembled; doors shaken and ladies alarmed; a trembling vibration; interval 10 minutes. |
| | ...do | ...do | 39 25 | 77 24 | | | | | A. B. Carty | Slight vibration, noticed by few. |
| 10 | Frostburgh | Allegany | 39 39 | 78 55 | 1 | SW. to NE. | | | H. R. Geiger (U. S. Geological Survey). | In bed, three-story brick house; horizontal undulation. Region undermined by coal mines, most of which fell in. Not generally noticed by people moving. |
| 11 | Hagerstown | Washington | 39 39 | 77 42 | 1 | | | 10 to 20 | J. P. Horter | Information obtained from others; Mr. Horter did not feel it; "felt distinctly, but rather light;" accompanied by low rumbling. |
| 12 | Hyattsville | Pr. George's | | | 2 | E. to W. | | 30 | E. M. Burchard | Undulatory; second shock lighest. |
| 13 | Jefferson | Frederick | 39 22 | 77 31 | 2 | | | | S. E. Little | Windows rattled; house rocked; inmates left house; felt more strongly in upper stories; felt generally throughout the village. |
| 14 | Knoxville | ...do | 39 20 | 77 38 | | | | | A. B. Carty | (Information obtained from others); very perceptible; windows rattled. |
| 15 | Libertytown | .. do | 39 30 | 77 14 | | | | | J. W. Etzler, postmaster. | Not felt. |
| 16 | Lime Kiln | ...do | 39 22 | 77 34 | | | | 5 or 6 | M. J. Grove | Jarring. |
| 17 | Manchester | Carroll | 39 39 | 76 55 | | | | | A. Shower, postmaster. | Slight shock or trembling; a few felt it. |
| 18 | Middletown | Frederick | 39 28 | 77 32 | | | | | A. B. Carty | (Information obtained from others); shock very perceptible; in some cases rattling windows. |
| 19 | Oakland | Garrett | 39 25 | 79 25 | 2 | | 1 | | P. Hamill, postmaster. | Very light; interval one minute; observer in house; rumbling noise; horizontal tremor; rocky ground. |
| 20 | Oxford | Talbot | 38 41 | 76 12 | | | | | R. E. Nelson | Duration about ten seconds; light, though generally felt in town (information from others). |
| 21 | Petersville | Frederick | 39 20 | 77 37 | | | | | W. P. Gardner, late postmaster. | Not felt. |
| 22 | Pikesville | Baltimore | 32 22 | 76 43 | | | | | | |
| 23 | Rose Hill | ...do | 32 22 | 76 43 | 2 | | | | C. R. Goodwin | First a tremor, then an undulation; doors and windows rattled. |
| 24 | Smithsburgh | Washington | 39 40 | 77 33 | 3 | | | | A. F. Diffendal | Short intervals; duration of each shock one-half minute; people were generally in bed and awakened; rattling of loose door-latches and windows; no unusual noise. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**MARYLAND—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | m. | s. | | |
| 25 | Solomon's Lamp Light-station. | | | | 2 | | | | L. D. Evans, keeper | "Intensity best described by No. 2." |
| 26 | Sykesville | Carroll | 39 22 | 77 00 | | | | | M. A. Cudlipp (U. S. Geological Survey). | Not felt; conditions for observation very favorable |
| 27 | Woodstock | Howard | 39 22 | 76 56 | | NNW. to SSE. | | | Signal Service observer. | Two or more shocks. |

**MASSACHUSETTS.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Amherst | Hampshire | 42 23 | 72 31 | | | | | W. M. D | Not felt. |
| 2 | Andover | Essex | 42 39 | 71 09 | | | | | do | Do. |
| 3 | Athol | Worcester | 42 36 | 72 14 | | | | | F. H. Albee | Do. |
| 4 | Blue Hill | Norfolk | 42 16 | 71 06 | | | | | H. H. Clayton, observer, Blue Hill Observatory. | Do. |
| 5 | Boston | Suffolk | 42 22 | 71 05 | | | | | Mary Irving | |
| | do | do | 42 22 | 71 05 | 1 | | | 12 | Hartford Courant, September 1, 1886. | On fifth floor of very tall and narrow building a tremulous movement was distinctly felt and on sixth floor dust was shaken from gas-pipes. |
| | do | do | 42 22 | 71 05 | | | | | New York Herald, September 1, 1886. | Not felt. |
| | do | do | 42 22 | 71 05 | | | | | Associated Press | Scarcely perceptible except in upper stories of lofty buildings. |
| | do | do | 42 22 | 71 05 | 1 | | | | Miss S. M. Burgess, teacher. | Felt. |
| 6 | Boston Light | do | | | | | | | T. Bates, keeper | Not felt. |
| 7 | Cape Ann | Essex | 42 38 | 70 39 | | | | | New York Herald, September 1, 1886. | Slightly felt. |
| 8 | Cape Cod | Barnstable | 41 41 | 70 04 | | | | | do | Do. |
| 9 | Cohasset | Norfolk | 42 15 | 70 49 | | | | | W. M. D | Not felt. |
| 10 | Concord | Middlesex | 42 27 | 71 20 | | | | | J. A. Haskell | Do. |
| 11 | Dighton | Bristol | 41 50 | 71 08 | | | | | E. Joeger | |
| 12 | Dorchester district | Suffolk | | | 2 | | | 15 | W. A. Macleod | No noise; duration of each shock four seconds. |
| 13 | Fitchburg | Worcester | 42 35 | 71 48 | | | | | W. M. D | Not felt. |
| 14 | Gilbertville | do | 42 19 | 72 11 | | | | | do | Do. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**MASSACHUSETTS—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | *m.* | *s.* | | |
| 15 | Greenfield | Franklin | 42 36 | 72 36 | | | 90 | 15 | G. R. Knapp | House trembled gently and chandelier swung; no noise. |
| 16 | Groton | Middlesex | 42 36 | 71 34 | | | | | W. M. D. | Not felt. |
| 17 | Gurnet Point Light-station. | Plymouth | 42 00 | 70 37 | | | | | M. Reamey, keeper of Minot's Ledge Light-house. | Do. |
| 18 | Holbrook | Norfolk | 42 09 | 71 02 | | | | | Mary P. Bates | Do. |
| 19 | Jamaica Plain | Suffolk | 42 19 | 71 06 | | SW. to NE. | | | E. H. Richards | Good observation. |
| 20 | Long Island Light-station. | ...do | 42 20 | 70 58 | | | | | T. H. Lyndon, keeper | Not felt. |
| 21 | Long Meadow | Hampden | 42 04 | 72 25 | | | | 48 | H. H. Emerson | Rattled windows, crockery, etc.; not noticed by the majority of people. |
| 22 | Lowell | Middlesex | 42 39 | 71 19 | | | | | W. M. D. | Not felt. |
| | ...do | ...do | 42 39 | 71 19 | | | | | J. B. Francis | Sends copy of record of telehydrobarometer on which the shock was indicated. |
| 23 | Manchester | Essex | 42 35 | 70 46 | | | | | W. M. D. | Not felt. |
| 24 | Minot's Ledge Light-station. | Norfolk | 42 15 | 70 51 | | | | | M. Reamey, keeper | Do. |
| 25 | Nantucket | Nantucket | 41 17 | 70 06 | | | | | A. B. Johnson, chief clerk Light-House Board. | Do. |
| 26 | Newburyport | Essex | 42 49 | 70 52 | | | | | W. M. D. | Do. |
| 27 | North Adams | Berkshire | 42 42 | 73 06 | | | | | C. H. Stevens | Bracket lamp swung violently. |
| 28 | Northfield | Franklin | 42 42 | 72 28 | | | | | W. M. D. | Not felt. |
| 29 | Osterville | Barnstable | 41 41 | 70 18 | | | | | Professor Miles, of the Massachusetts Institute of Technology. | Not felt; conditions of observation very favorable. |
| 30 | Pittsfield | Berkshire | 42 27 | 73 12 | | | | | W. M. D. | Not felt. |
| 31 | Somerville | Middlesex | 42 25 | 71 07 | | | | | ...do | Do. |
| 32 | Springfield | Hampden | 42 08 | 72 35 | 3 | | | | S. A. Hyde | Distinct shocks. |
| | ...do | ...do | 42 08 | 72 35 | | | | | Associated Press, September 1, 1886. | Very faint. |
| 33 | Stockbridge | Berkshire | 42 18 | 73 20 | | | | 90 | J. O. Jacob | Felt. |
| 34 | Taunton | Bristol | 41 54 | 71 06 | | | | | E. A. Jones, M. D | Not felt. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**MICHIGAN.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | *m.* | *s.* | | |
| 1 | Adrian | Lenawee | 41 54 | 84 04 | | | | | Rev. J. Cost, M. D | Not felt. |
| 2 | Ann Arbor | Washtenaw | 42 17 | 83 47 | | | | | C. Rominger | Professor Schaeberte, in observatory, lower floor, felt shock. Revolving cupola of observatory set in motion with rattling, startling the professor. Later on plastering fell from walls (letter No. 2); "Not felt," said letter No. 1. Newspaper extract: "Earthquake moving from E. to W. sprung up; several ladies at Cutter House terrified and left room. |
| | ......do | ....do | 42 17 | 83 47 | | | | | J. M. Schaeberly | |
| 3 | Au Sable Light | | | | | | | | T. Henrickson | Not felt. |
| 4 | Bad Axe | Huron | 43 48 | 82 58 | | | | | J. T. Rorick, postmaster. | Do. |
| 5 | Charity Island Light | ....do | 44 01 | 83 23 | | | | | C. McDonald | Do. |
| 6 | Detroit | Wayne | 42 19 | 83 03 | | | | | Baldwin | |
| | ......do | ....do | 42 19 | 83 03 | | | | | Associated Press | Considerable excitement; short duration; distinctly felt in different parts of town. In Free Press building editorial force made stampede for street; weekly men all stopped work; those on piece-work kept on. |
| | ......do | ....do | 42 19 | 83 03 | 3 | W. to E | 3 | | Chicago Inter-Ocean and Chicago Herald, September 1, 1886. | Felt in all parts, especially in high buildings; large buildings, chairs, tables, pictures, and gas-fixtures shaken and standing persons nearly thrown down. In Free Press building, etc., same as "Associated Press." Work in newspaper offices temporarily suspended. |
| | ......do | ....do | 42 19 | 83 03 | | | | | New York Times, September 1, 1886. | Very distinct shock; felt exclusively along river front and back to City Hall; seemed to follow course of river; recognized at once by experienced persons; chandeliers shaken, vases, etc., swayed, pictures disturbed, and nervous people frightened; brief duration. |
| | ......do | ....do | 42 19 | 83 03 | 1 | E. to W | | | Detroit Tribune, September 1, 1886. | Party in room; floor and walls shook, pictures and chandeliers swayed; had experienced earthquakes and recognized the vibration; felt shock very forcibly, and thinks direction was from E. to W. or W. to E. |

*Report of earthquake observations, earthquake of August 31, 1886*—Continued.

**MICHIGAN—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | m. | s. | | |
| | Detroit | Wayne | 42 19 | 83 03 | 2 | E. to W | | 9 | Detroit Tribune, September 1, 1886. | Party reading heard noise, not rumbling, but as of a pounding against the walls; house swayed NNW. to SSE; first shock lasted three seconds; interval three seconds; second shock lasted three seconds; generally felt in upper stories throughout city; not generally felt on ground floors; seemed to follow course of river and hardly felt beyond Larned street. |
| | ......do | ....do | 42 19 | 83 03 | 3 | W. to E | 3 | | Detroit Free Press, September 1, 1886. | Low rumbling as of distant thunder, followed by a quake; felt all over city; buildings swayed and occupants rushed to the streets; second shock immediately after and more severe, and soon a third and slight. On upper floors of large blocks all movable objects as chairs, tables, etc., had been moved; chandeliers swung W. to E. |
| | ......do | ....do | 42 19 | 83 03 | 3 | E. to W | | | Mrs. L. H. Trowbridge | First interval, five minutes; second, same; second shock heaviest. |
| | ......do | ....do | 42 19 | 83 03 | | | | | Robert McCulloch | |
| | ......do | ....do | 42 19 | 83 03 | 3 | | | 10 or 15 | Signal Service observer. | Slight, but distinct; low rumblings like thunder. |
| 7 | Detroit River Light, Bar Point. | | | | 2 | | 2 | | R. Oldrey, keeper | In watch-room of light-house, on stone pier, built in 22 feet of water, chair shook and clock jarred horizontally; noticed by self and assistant; "very light." |
| 8 | East Saginaw | Saginaw | 43 27 | 83 57 | 1 | | | 15 | Detroit Abend Post, September 1, 1886. | Noticed by several; thought it an explosion at the salt-works. |
| | ......do | ....do | 43 27 | 83 57 | | | | 15 | Detroit Free Press, September 1, 1886. | |
| 9 | Escanaba | Delta | 45 44 | 87 04 | | | | | Signal Service observer. | Not felt. |
| 10 | Fort Gratiot Light-station. | St. Clair | 42 58 | 82 26 | | | | | I. T. Palmer, keeper | Do. |
| 11 | Grand Haven | Ottawa | 43 04 | 86 13 | | E. to W | | | Detroit Abend Post, September 1, 1886. | Lady guests left rooms in fright and fled to parlor of hotel. |
| | ..... do | ....do | 43 04 | 86 13 | 2 | ....do | | 5 | Detroit Free Press, September 1, 1886. | Interval two seconds. |
| 12 | Grand Haven Light-station. | ....do | 43 00 | 86 22 | | | | | E. Davidson, keeper | Not felt. |
| 13 | Grande Pointe au Sable Light-station. | Mason | 44 10 | 86 30 | | | | | H. L. Hanson, keeper | Not felt. |
| 14 | Grand Rapids | Kent | 42 59 | 85 40 | | | | | | |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**MICHIGAN—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | | | | |
| 15 | Hersey | Osceola | 43 51 | 85 26 | | | | | S. R. Jones, postmaster | Some thought they heard row rumbling, buct th most reliable neither heard nor felt. |
| 16 | Kalamazoo | Kalamazoo | 42 18 | 85 33 | 1 | | | | Signal Service observer | "Slight shock." |
| 17 | Lansing | Ingham | 42 44 | 84 36 | | | | | R. C. Carpenter | Not felt. |
| 18 | Lapeer | Lapeer | 43 03 | 83 19 | | | | | John Abbott, postmaster. | Do. |
| 19 | Manistee Light-station | Manistee | 44 13 | 86 19 | 1 | | | | J. H. Roberts, keeper | New clock facing SSW., wife sitting near; house shook and pendulum struck the glass; clock stopped. |
| 20 | Marshall | Calhoun | 42 17 | 84 59 | | | | | S. P. Lacey, postmaster. | Not felt. |
| 21 | Muskegon Light-station. | | | | | | | | C. A. Lindstrem, keeper | Do. |
| 22 | Petite Pointe au Sable Light-station. | | | | | | | | G. Buttars, keeper | Do. |
| 23 | Point Betsey Light-station. | | | | | | | | E. R. Slyfield, keeper | Do. |
| 24 | Port Austin Light | | 44 10 | 83 00 | | | | | F. E. Kimball, keeper | Do. |
| 25 | Prentis' Bay | Mackinac | 45 59 | 84 13 | | | | | J. S. Lawrence | Not felt; conditions for observation favorable. |
| 26 | Port Huron | St. Clair | 42 56 | 82 26 | | | | | New York World, September 2, 1886. | |
| 27 | Sandusky | Sanilac | 43 24 | 82 47 | | | | | T. Doyle, postmaster | Not felt. |
| 28 | South Manitou Light-station. | Manitou | 45 02 | 76 07 | | | | | M. Knudser, keeper | Do. |
| 29 | Traverse City | Grand Traverse. | 44 45 | 85 37 | | | | | M. L. Leach | No information of a shock felt in this part of State. |
| 30 | Saginaw River Range Lights. | Saginaw | 43 40 | 83 51 | | | | | W. H. Munshaw, keeper. | Not felt. |
| 31 | St. Clair Flats Lights, Algonac. | St. Clair | 42 35 | 82 33 | | | | | S. A. Warner, keeper | Do. |
| 32 | Thunder Bay Sound Light. | Alpena | 45 00 | 83 10 | | | | | J. Sinclair, jr., keeper. | Do. |

**MINNESOTA.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Rochester | Olmstead | 44 02 | 92 31 | | | | | S. D. Wolf, postmaster. | Not felt. |
| 2 | Waseca | Waseca | 44 14 | 93 34 | | | | | J. F. Murthy | Do. |
| 3 | Northfield | Rice | 44 27 | 93 12 | | | | | Prof. L. W. Chaney | Not felt; vague reports of tremors. |

*Report of earthquake observations, earthquake of August 31, 1886*—Continued.

**MISSISSIPPI.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | *m.* | *s.* | | |
| 1 | Agricultural College | Oktibbeha | | | 1 | | | | J. A. Myers, State chemist. | Duration, a few seconds; light, noticed by few. |
| 2 | Batesville | Panola | 34 19 | 89 54 | 2 | | | | H. Harris | Duration of each, twenty seconds; interval, fifteen seconds; windows rattled; glassware fell from bureau; majority of people did not feel it; no damage. |
| 3 | Bay St. Louis | Hancock | 30 18 | 89 20 | | | | | New Orleans Picayune, September 5, 1886. | |
| 4 | Biloxi | ....do | 30 25 | 88 53 | | | | | ......do | |
| 5 | Brookhaven | Lincoln | 31 32 | 90 24 | | | | | V. L. Tyler, postmaster. | Not felt. |
| 6 | Columbus | Lowndes | 33 28 | 88 23 | | | | | Louisville Commercial, September 1, 1886. | Regulators and clocks all stopped. |
| | ......do | ....do | 33 28 | 88 23 | | | | | D. Hale, postmaster | |
| 7 | Corinth | Alcorn | 34 54 | 88 28 | | | | 30 | T. E. Henry | No noise; in three-story brick building; undulatory. |
| 8 | Enterprise | Clarke | 32 10 | 88 45 | | | | | Rev. E. S. Robinson | Felt. |
| 9 | Forest | Scott | 32 21 | 89 28 | | | | | New Orleans Picayune, September 2, 1886. | |
| 10 | Grenada | Grenada | 33 46 | 89 45 | 1 | | | 35 to 45 | R. N. Hall, postmaster | Noticed by few; chandeliers swung and plastering cracked in two houses. |
| 11 | Hazlehurst | Copiah | 31 52 | 90 20 | | | | | F. M. Serton | Not felt within 30 miles. |
| 12 | Holly Springs | Marshall | 34 45 | 89 21 | | | | | New Orleans L'Abeille, September 3, 1886. | |
| 13 | Houston | Chickasaw | 33 52 | 88 59 | | | | | J. M. Griffin, postmaster. | Not felt. |
| 14 | Jackson | Hinds | 32 17 | 90 10 | | | | | F. M. Serton, postmaster at Hazlehurst. | "Said to have been felt by a few." |
| | ......do | ....do | 32 17 | 90 10 | | | | | New Orleans Picayune, September 2, 1886. | |
| | ......do | ....do | 32 17 | 90 10 | | | | | New York Tribune, September 2, 1886. | "Felt here." |
| 15 | Lexington | Holmes | 33 04 | 90 00 | | | | | New Orleans L'Abeille, September 3, 1886. | |
| 16 | Lula | Coahoma | | | | | | | New Orleans Picayune, September 2, 1886. | |
| 17 | Meridian | Lauderdale | 32 21 | 88 40 | | | | | ......do | |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**MISSISSIPPI—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | *m.* | *s.* | | |
| | Meridian | Lauderdale | 32 21 | 88 40 | | | | | New York Times | Perceptible. |
| 18 | Natchez | Adams | 31 34 | 91 20 | | | | | Natchez Daily Democrat, September 1, 1886. | Not felt; diligent inquiry made. |
| | ......do | ....do | 31 34 | 91 20 | | | | | W. A. Davis, city editor | Not felt; careful inquiry made. |
| 19 | Oxford | La Fayette | 34 21 | 89 25 | | | | 30 | New Orleans Democrat, September 3, 1886. | Very perceptible, especially at the university observatory; windows rattled, chandeliers swung, and some made unsteady. |
| | ......do | ....do | 34 21 | 89 25 | | NE. to SW. | 1 | | R. B. Fulton, of observatory of State University. | No noise; strata of sand and clay several hundred feet thick; elevation, 510 feet. |
| 20 | Shaw | | | | | | | | New Orleans Picayune, September 2, 1886. | |
| 21 | Tunica | Tunica | 34 46 | 90 20 | | | | | ......do | |
| 22 | Tupelo | Lee | 34 14 | 88 35 | 1 | | | | F. M. Goar, postmaster | Duration, very brief; very slight; sandy loam, clay foundation; no noise. |
| 23 | Vicksburg | Warren | 32 20 | 90 50 | | N. to S. | 1 | | Associated Press | City hall, a frail building, on high brick supports, rocked so much that the city council hastily adjourned; not noticed by those on the ground; duration, about one minute. |
| | .....do | ....do | 32 20 | 90 50 | 2 | | | | Signal Service observer | Distinct shocks, neither lasting over forty-five seconds. |
| 24 | West | Holmes | 33 09 | 89 45 | | | | | Mrs. M. E. Drake. | Not felt. |

**MISSOURI.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | *m.* | *s.* | | |
| 1 | Alton | Oregon | 36 45 | 91 21 | | | | | J. E. Mosely, postmaster. | Not felt. |
| 2 | Bloomfield | Stoddard | 36 56 | 89 55 | | | | | G. H. Crosser, postmaster. | Felt very perceptibly by a majority of people: short duration; no damage; no noise. |
| 3 | Columbia | Boone | 38 58 | 92 27 | 2 | | | | Prof. J. W. Spencer | Noticed in house on high hill. |
| | ......do | ....do | 38 58 | 92 27 | | | | | Prof. R. E. Call | "Not felt within 50 miles." |
| 4 | Eminence | Shannon | 37 12 | 91 20 | | | | | J. A. Jadwin, postmaster. | Not felt. |
| 5 | Fairville | Saline | | | 1 | | | 2 or 3 | H. G. Harvey | No noise; undulatory. |
| 6 | Fayette | Howard | 39 09 | 92 43 | | | | | Prof. F. B. Smith | Not felt. |
| | ......do | ....do | 39 09 | 92 43 | | | | | Prof. J. W. Kilpatrick. | Do. |
| 7 | Glasgow | ....do | 39 13 | 92 53 | | | | | Prof. F. B. Smith | Do. |

*Report of earthquake observations, earthquake of August 31, 1886*—Continued.

**MISSOURI—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | m. | s. | | |
| 8 | Hannibal | Marion | 39 41 | 91 28 | | | | | Associated Press | Walls of brick buildings trembled and swayed; one or two meetings hastily adjourned. |
| | do | do | 39 41 | 91 28 | | | | | Weekly Gate City, September 2, 1886. | A Hannibal local paper says: Buildings, especially brick, swayed; windows shook, and a distant rumbling was heard; all the members of a lodge rushed from the building; distinctly felt in gallery of opera-house and Journal composing room |
| 9 | Jefferson City | Cole | 38 37 | 92 09 | | | | | W. E. Coleman, superintendent public schools. | Not felt. |
| 10 | Kansas City | Jackson | 39 06 | 94 36 | | | | | B. Smith | Do. |
| | do | do | 39 06 | 94 36 | | | | | Associated Press | Do. |
| | do | do | 39 06 | 94 36 | | | | | W. H. Reed | "Not felt within 100 miles." |
| | do | do | 39 06 | 94 36 | | | | | W. H. R. Lynkins | A very few, afterward thought they felt shock and heard low roaring. |
| 11 | Louisiana | Pike | 39 27 | 91 03 | | | | | Missouri Republican | A severe shock, causing a panic; brick walls swayed and trembled, and furniture moved perceptibly; guests left hotels and a lodge in a third story hastily adjourned. |
| 12 | Marshall | Saline | 39 07 | 93 14 | 1 | SE. to NW. | | 4 to 5 | H. G. Harvey | Decided shock; house moved horizontally; no noise. |
| 13 | Mexico | Audrain | 39 12 | 91 53 | | | | | J. F. Llewellyn | Not felt. |
| 14 | Milan | Sullivan | 40 12 | 93 10 | | | | | S. M. Grigsby, postmaster. | Do. |
| 15 | New Madrid | New Madrid | 36 36 | 89 32 | | | | | C. A. Laforge, postmaster. | Vibrations very distinct; rocking-chairs rocked gently; almost unnoticed at the time, as several slight shocks occur every year. |
| 16 | North Springfield | Greene | | | | | | | P. Roulet | "Not felt in this region." |
| 17 | St. Louis | St. Louis | 38 39 | 90 14 | | | | | Associated Press | A very distinct shock; duration, one-fourth of a minute; not at all violent, and decidedly undulatory; guests in upper rooms of hotels rushed down-stairs, badly frightened; pictures swung; tables swayed; some felt dizzy; most noticeable in high buildings. |
| | do | do | | | | | | | Missouri Republican, September 1, 1886. | Felt quite plainly; duration exceedingly brief, but created quite a sensation in some buildings. |
| | do | do | | | | | | | W. H. Cutting | Not felt; he and wife were walking on street. |
| | do | do | | | 1 | | | | Signal Service observer | No noise. |
| 18 | Sedalia | Pettis | 38 44 | 93 13 | | | | | Prof. J. W. Kilpatrick. | (Information from others); not felt. |
| 19 | Springfield | Greene | 37 16 | 93 16 | | | | | E. M. Shepard, geologist. | Not felt in this vicinity. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**MISSOURI—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration, m. | Duration, s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | | | | |
| 20 | Steelville | Crawford | 38 01 | 91 19 | | | | | —— Jackson, postmaster. | Not felt. |
| 21 | Union | Franklin | 38 28 | 90 59 | | | | | H. Arand, postmaster | Do. |
| 22 | Warrenton | Warren | 38 49 | 91 07 | | | | | H. Parker, postmaster | Do. |
| 23 | Waynesville | Pulaski | 37 53 | 92 12 | | | | | J. R. Burchard, postmaster. | Do. |

**NEW HAMPSHIRE.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration, m. | Duration, s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Alton | Belknap | 43 28 | 71 14 | | | | | W. M. D | Not felt. |
| 2 | Bristol | Grafton | 43 36 | 71 48 | | | | | do | Do. |
| 3 | Concord | Merrimack | 43 12 | 71 32 | | | | | G. W. Crocket, postmaster. | Do. |
| 4 | Deerfield | Rockingham | 43 07 | 71 14 | | | | | W. M. D. | Do. |
| 5 | Dover | Strafford | 43 12 | 70 53 | | | | | do | Do. |
| 6 | East Andover | Merrimack | 43 27 | 71 45 | | | | | do | Do. |
| 7 | Epping | Rockingham | 43 12 | 71 04 | | | | | do | Do. |
| 8 | Epsom | Merrimack | 43 13 | 71 19 | | | | | do | Do. |
| 9 | Henniker | do | 43 10 | 71 49 | | | | | C. L. Whittle | Felt no jar, only noise. |
| 10 | Manchester | Hillsborough | 43 01 | 71 28 | | | | | S. D. Land | Distinct rumbling. |
| | do | do | 43 01 | 71 28 | | | | | W. M. D | Noise and slight vibration. |
| 11 | Meredith Center | Belknap | 43 39 | 71 31 | | | | | do | Not felt. |
| 12 | Merrimack | Hillsborough | 42 52 | 71 29 | | | | | do | Do. |
| 13 | Nashua | do | 42 46 | 71 28 | | | | | do | After reading of it, two persons thought they had felt a shock. |
| 14 | New Castle | Rockingham | 43 04 | 70 43 | | | | | B. Wendell, of Harvard College. | Not felt. |
| 15 | Nottingham | do | 43 05 | 71 07 | | | | | Derry News | A shock was felt. |
| 16 | Portsmouth | do | 43 04 | 70 47 | | | | | S. J. Gerrish, postmaster. | Not felt. |
| 17 | Quincy | Grafton | 43 46 | 71 47 | 4 | | 4 | | W. M. D | Very light. |
| 18 | Rochester | Strafford | 43 17 | 70 58 | | | | | do | Not felt. |
| 19 | Union | Carroll | 43 35 | 71 12 | | | | | do | Rumbling; Monday evening. |
| 20 | Walpole | Cheshire | 43 05 | 72 27 | | | | | do | Not felt. |
| 21 | Wolfborough | Carroll | 43 35 | 71 12 | | | | | do | Do. |
| 22 | Wolfborough Junction | do | 43 34 | 71 02 | | | | | do | Do. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**NEW JERSEY.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | | | | |
| 1 | Absecon | Atlantic | 39 26 | 74 25 | | N. to S. | 1 | | Light house keeper | First motion up and down, with slight lateral motion N. to S.; series of shocks. |
| 2 | Atlantic City | do | 39 23 | 74 25 | 1 | | 1 | | Chicago Herald, September 2, 1886. | Keeper in top of light-house; it began to sway; he could not walk; grasped the stair-way rail; saw many hundreds of birds dash against the panes, which they dyed with blood; after fifteen seconds rocking increased; lamp swung as never before; chains, ropes, instruments, and clock rattled against the walls. |
| | do | do | 39 23 | 74 25 | | | | | A. B. Johnson, chief clerk Light-House Board, Washington, D. C. | Very interesting reports from light-house keepers. |
| | do | do | 39 23 | 74 25 | 1 | | | | H. W. Hartley | Tall pendulum clock stopped; lady in third story hotel only one who noticed it; the noise of disturbed birds noticed by several. |
| | do | do | 39 23 | 74 25 | | | | | Light-house keeper | |
| | do | do | 39 23 | 74 25 | | | | | A. C. Trippe | On pier, at entertainment; it vibrated shoreward and seaward; one-third the audience left, thinking the pier was moving away. |
| 3 | Barnegat City | Ocean | 39 46 | 74 13 | | N. to S. | | | A. B. Johnson, chief clerk Light-House Board, Washington, D. C. | Very interesting reports from light-house keepers; one says series of shocks, causing strong vibrations N. to S., and another, a strong shock. |
| 4 | Bay Head | do | 40 04 | 74 02 | | E. to W. | | | Rev. E. R. Craven | Several tremors, probably three; distinct noise; seated by table, ground floor; heard cracking as of furniture; hanging lamp did not move; in cottage on brick foundation, 100 yards from high-water mark, only few people felt light tremor; lady rocking in chair N. to S. noticed a distinct E. to W. motion. |
| 5 | Belvidere | Warren | 40 50 | 75 05 | 5 | E. to W. | | | G. Holstein | First shock lasted five minutes; second, one minute; third, two minutes; fourth, very slight; fifth, barely perceptible; windows shaken; water in vessels agitated. |
| 6 | Bloomfield | Essex | 40 48 | 74 11 | | | | 20 | C. E. McDowell | In rocking-chair, reading. Newspaper, hands, chair, bureau, and house shook. On second floor. |
| 7 | Bordentown | Burlington | 40 09 | 74 42 | | | | | Trenton Daily True American, September 2, 1886. | "Bordentown was visibly affected." |
| | do | do | 40 09 | 74 42 | | | | | J. H. Brakeley, Ph. D. | "Light." No noise. House on high ground 60 feet above Delaware River. Lady had sensation as though about to have stroke of apoplexy. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**NEW JERSEY—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | m. | s. | | |
| 8 | Bridgeton | Cumberland | 39 26 | 75 14 | | | | | New York World, September 1, 1886. | Quite severe; three-story bricks rocked as if at sea. It is feared the walls were injured. |
| 9 | Burlington | Burlington | 40 04 | 74 51 | 2 | | 2 | 30 | Dr. N. R. Bradner, member American Academy Natural Science, etc. | First shock lasted two minutes; interval twelve minutes; second less severe; lasted thirty seconds. On second floor, north wing, large frame house, 1 mile east of Delaware River; bed shook; house trembled; toilet articles on bureau knocked against each other. Scarcely a dozen others in town felt it. |
| | do | do | 40 04 | 74 51 | 3 | N. to S. | 1 | | G. A. Appleton | On first floor; first shock lasted one minute; windows and door shook; interval fourteen minutes; second more severe; N. to S.; lamp swayed; alarm-clock rang; horses in stable grew restless; second interval twenty-one minutes; third shock shook windows. |
| 10 | Camden | Camden | 39 56 | 75 07 | | | 2 | | New York World, September 1, 1886. | Hundreds left houses, some in night-dresses. Some say houses at a height of 15 feet rocked 10 inches. Crockery broken; pictures and glasses swayed from hangings. The shocks generally believed to be an explosion of powder. |
| 11 | Cape May | Cape May | 39 58 | 74 56 | 1 | | | 3 | New York World, September 2, 1886. | "Sensibly felt." |
| | do | do | 39 58 | 74 56 | | NW. to SE. | | | E. W. Kirby | Peculiar electrical sensation; felt in several cottages. Bed trembled several seconds; two ladies frightened by movement of bed and ran out. |
| 12 | Eatonton | Monmouth | 40 18 | 74 03 | | | | | D. H. Morris | Not felt. |
| 13 | Elmer | Salem | 39 36 | 75 09 | | | | | New York World, September 1, 1886. | Houses swayed; clocks stopped; dishes and crockery rattled and broken. |
| 14 | Freehold | Monmouth | 40 15 | 74 16 | | | | | S. Lockwood, county superintendent. | Made careful inquiry; not felt. |
| 15 | Hackensack | Bergen | 40 53 | 74 03 | 1 | | | | New York World, September 1, 1886. | "A very violent shock." |
| | do | do | 40 53 | 74 03 | | E. to W. | | | I. H. Andrews | Undulatory; windows shook; chandeliers swung; pendants on candelabrum jingled. Interval twenty or thirty minutes. Second less severe; in one house piece of ceiling jarred off; many persons nauseated, clutched their chairs, etc.; some clocks stopped. Hardly felt across the river, east; most severe in upper and northern portion of town. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**NEW JERSEY—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | *m.* | *s.* | | |
| 16 | Hightstown | Mercer | 40 16 | 74 32 | | | | | Anonymous | Felt by several, but very light. |
| 17 | Hoboken | Hudson | 40 44 | 74 02 | | | | | G. F. Kunz, mineralogist. | Party scientific men seated at desk, parlor floor, staunch house, solid ground, 40 feet from river, reading, writing, or quietly talking. Felt no shock. |
| 18 | Jersey City | ...do | 40 42 | 74 2 | 1 | | | | New York World, September 1, 1886. | Crockery and bric-a-brac damaged; consternation at the tremulous motion of the wave; people left houses; vague and conflicting stories of its first appearance. Party lying on lounge in deep thought felt subtle sensation of being gently shaken and the next instant was rolled to the floor with great force; his wife, in kitchen, at work, standing, was thrown down with much greater force; rushing in, he found her crouching terror-stricken in the corner. Many similar experiences on same street. |
| 19 | Keyport | Monmouth | 40 26 | 74 11 | | | | | Rufus Ogden | Noticed by very few. Slight rattling of lamp, etc. |
| 20 | May's Landing | Atlantic | 39 28 | 74 43 | | | | | J. S. Veal, postmaster. | Not felt. |
| 21 | Millville | Cumberland | | | | | | | New York World, September 1, 1886. | Very distinct. |
| 22 | Moorestown | Burlington | 39 58 | 74 57 | | SE. to NW | | 25 | J. C. Beans | First floor, strong frame house, facing SE., on sand and clay. Very few neighbors noticed it. No noise. Less violent than shock of August, 1884. |
| | ...do | ...do | 39 58 | 74 57 | | | | | J. R. Runyon | "Not noticed at the time, so far as I can learn." |
| | ...do | ...do | 39 58 | 74 57 | 3 | | | | New York Tribune, September 2, 1886, | Intervals three minutes each; much alarm; bells rung; bric-a-brac and vases thrown down and houses shaken. |
| | ...do | ...do | 39 58 | 74 57 | | SW. to NE | | 40 | H. D. Noyes, M. D | In second story, frame house; gentle quivering for forty seconds, with possibly a short interval. In chair facing SE., motion from side to side; servants alarmed in third story. |
| 23 | Navesink Highlands Light-station. | Monmouth | 40 23 | 73 58 | | | | | D. B. Calkins, keeper | Not felt. |
| 24 | Newark | Essex | 40 44 | 74 10 | | E. to W | | 3 or 4 | Elbert R. Ball | In bed, third floor; bed swung E. to W.; bowl and pitcher rattled; women frightened and nauseated; clock stopped; no noise; one swing and a shake. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**NEW JERSEY—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | m. | s. | | |
| | Newark | Essex | 40 44 | 74 10 | 1 | | | | New York Tribune, September 1, 1886. | Large factories shaken violently; not generally felt. At electric-light works in Harrison, opposite Newark, watchman saw building tremble and sway; swinging-lamps swayed; watchman left building. At Clark's thread works, Newark side, severely felt; watchman says entire building shook; lasted three minutes; machinery swayed; I thought the floor would cave in and the building fall. Those in vicinity of factory felt jar; not felt at electric-light works. |
| | ......do | ....do | 40 44 | 74 10 | | S. to N | | 15 | F. Schmatstich | On sofa, in third story, frame house. Recognized a very slight tremor, as an earthquake; waving motion increasing in intensity and suddenly stopping. Felt by very few. |
| | ......do | ....do | 40 44 | 74 10 | | | | | New York Sun, September 1, 1886. | Felt by watchmen in factories. In all cases referred to local causes. One in revolving-chair had his head knocked against wall and left building. |
| 25 | New Brunswick | Middlesex | 40 29 | 74 27 | | | | | New York World, September 2, 1886. | Felt only on high ridge in center of city. |
| | ......do | ....do | 40 29 | 74 27 | | | | | New York Tribune, September 2, 1886. | Felt by few who live on high ridge in center of city. |
| | ......do | ....do | 40 29 | 74 27 | | | | | G. H. Cook | Not able to learn that any one felt shock. |
| | ......do | ....do | 40 29 | 74 27 | | | | | R. B. Blanvert | Noticed peculiar condition of atmosphere at sundown. |
| 26 | Orange | Essex | 40 46 | 74 14 | 1 | | | 15 | P. E. Bogert | No noise; slight shaking of bureau and oil in lamp; lasted fifteen seconds or less. "Very light." Felt by three persons in house; not felt by those in motion. |
| 27 | Paterson | Passaic | 40 55 | 74 10 | | | | | New York Tribune, September 2, 1886. | "Felt by few." |
| 28 | Pemberton | Burlington | 39 58 | 74 39 | 2 | | | | L. W. Cushman, a student at Cambidge, Mass. | In bed on second floor. Peculiar pulsating sensation. During second shock bed and house trembled gently; lamp-shade rattled. |
| 29 | Plainfield | Union | 40 37 | 74 25 | | | 1 to 1 | 00 30 | F. H. Meyer | On second floor, brick building; chandeliers swung slightly for one and a half minutes; bureau, looking-glass, and other light objects oscillated. No noise. Undulatory. |
| | ......do | ....do | 40 37 | 74 25 | 1 | N. to S | 2 | | Associated Press, September 1, 1886. | Vibrations gentle and increasing in intensity; chandeliers swung violently, and wood-work of brick houses creaked. People much alarmed. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**NEW JERSEY—Continued.**

| No | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | | | | |
| | Plainfield | Union | 40 37 | 74 25 | | | | | G. H. Cook | Noticed by some, though slight. |
| | ...do | ...do | 40 37 | 74 25 | 3 | | | 20 | G. H. Frost, civil engineer. | In chair, on first floor, reading. Violent shaking of house; no shaking of furniture, dishes, etc.; no clocks stopped; no bells rung. |
| 30 | Seabright | Monmouth | 40 21 | 73 58 | | | | | R. S. Harris, civil engineer. | Four miles north of Long Branch. Awakened by severe shaking of staunch wooden building. |
| 31 | Shamong | Burlington | 39 48 | 74 31 | | | | | B. O. Wade | Door vibrated for two seconds; a few minutes later upstairs window rattled. Noticed by one other. Not generally felt. Soil, sand. |
| 32 | South Orange | Essex | 40 44 | 74 16 | | | | | W. J. Chandler | Not felt in immediate vicinity. |
| 33 | Trenton | Mercer | 40 13 | 74 46 | | | | | Trenton Daily True American, September 2, 1886. | Felt by many; a few frightened; rumbling; generally noticed. In places pictures, looking-glasses, and furniture shook; no damage; unusual disturbance of river. |
| | ...do | ...do | 40 13 | 74 46 | 1 | | | | Daily True American, September 1, 1886. | Peculiar rumbling; building shook; knew it to be an earthquake. |
| 34 | Woodbury | Gloucester | 39 50 | 75 09 | 2 | | | 6 | Edward Brown | Only a slight tremor. |
| | ...do | ...do | 39 50 | 75 09 | | | | | New York World, September 1, 1886. | Many awakened and frightened to the streets; plainly felt. |

**NEW YORK.**

| No | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Albany | Albany | 42 40 | 73 45 | 4 | | | | Associated Press | Slight but distinct shocks; duration, two to five seconds; no damage. |
| | ...do | ...do | 42 40 | 73 45 | | | | | Albany Evening Journal, September 1, 1886. | Professor Egbert, of the Dudley Observatory, sat at his desk from 9.50 to 10.10 and did not feel any shock. The shock was generally felt, being most severe in the western part of the city. A gentle tremor, shaking small articles from shelves, followed at intervals by others, which threatened to snap chandeliers and demolish dwellings. The streets filled with people, talking about the earthquake; many thought it an explosion, and one the report of a gun with its echoes. |
| | ...do | ...do | 42 40 | 73 45 | | | | | V. Calvin, civil engineer. | Felt in many parts of the city. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

NEW YORK—Continued.

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | | | | |
| | Albany | Albany | 42 40 | 73 45 | 2 | NW. to SE | | | J. M. Clarke | In three-story brick building, about 150 feet above river, on horizontal clay bed 40 feet thick; mortar fell down chimney, house creaked; counted four wave crests, followed by irregular shaking; caused consternation in the family; first shock lasted thirty-five seconds; in some parts of the city four shocks were felt; good observations as to direction. |
| | ......do | ..do | 42 40 | 73 45 | | | | | Prof. J. Hall | Daughter in bed; heard noise, as if the sliding doors in the parlor were being moved, followed immediately by a trembling or rocking of her bed. |
| | ......do | ....do | 42 40 | 73 45 | | | | | W. G. Tucker, professor chemistry, etc., Albany Medical College. | "An undulatory swaying movement, as if the house were off its foundations and swayed in mid air." Was sitting in rocking chair, facing east, in the middle of the room, on the first floor, and was alone; no noise; house seemed to rise and roll from E. to W.; no jar or tremor; glass pendants on mantel chandelabra, 8 inches long and one-half inch apart, swung very decidedly, but did not jingle. My wife, moving about in second story, did not notice it. No damage, but many were awakened from sleep. |
| 2 | Balmville | Orange | 41 30 | 73 59 | | | | | New York Times | |
| 3 | Barber's Point Lighthouse. | Essex | 44 09 | 73 22 | | | | | C. E. Stevens, keeper. | Not felt. |
| 4 | Bath Beach | Kings | | | | | | | New York Tribune, September 2, 1886. | Do. |
| 5 | Binghamton | Broome | 42 07 | 75 53 | 3 | | | | Rev. J. W. Capen | Slight shocks; undulatory. |
| | ......do | ....do | 42 07 | 75 53 | 3 | | | | P. G. McFighe | "Distinct occurrences; one-half inch movement." |
| 6 | Blue Mountain Lake | Hamilton | 43 49 | 74 20 | | | | | E. Holden, M. D. Ph. D., etc. | Servant in two-story cottage felt house shake and ran down-stairs; felt distinctly on second floor of hotel; many felt slight giddiness and nausea; I was on the ground and did not feel it. |
| 7 | Bluff Point Lighthouse. | Yates | 42 37 | 77 04 | | | | | M. J. Herwerth, keeper | Not felt. |
| 8 | Bolton | Warren | 43 33 | 73 44 | | | | | Dr. De Forest Willard. | Mrs. Willard, lying quietly on wire-spring mattress in third story, frame building, on Green Island, was startled by very peculiar vibrations; no one else at hotel felt shock, as there was considerable noise. |

*Report of earthquake observations, earthquake of August 31, 1886*—Continued.

**NEW YORK—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | *m.* | *s.* | | |
| 9 | Brooklyn | Kings | 40 41 | 73 56 | | | | 2 or 3 | Prof. D. E. Bardwell | Was walking at about center of Brooklyn Bridge with two ladies; all felt the walk yield and rise two or three times as though the cable had been tightened and loosened; the river, previously smooth, became covered with white-caps. |
| | do | do | 40 41 | 73 56 | | | | | J. D. Bell, attorney | Conditions for observation very favorable, but did not notice it. On first floor, brick house (85 Keap street); chandeliers unaffected, although easily shaken by heavy wagons on the street. |
| | do | do | 40 41 | 73 56 | | | | | F. Frost | Not felt in neighborhood. |
| | do | do | 40 41 | 73 56 | | WSW. to ENE | 1 | | S. S. Guy, M. D | Drop-light from chandelier swung; not recognized as an earthquake. |
| | do | do | 40 41 | 73 56 | 3 | E. to W | | | F. E. Haines | First interval, ten minutes; second shock slight, and third moderate; chandeliers swung; some ladies felt dizzy and faint. |
| | do | do | 40 41 | 73 56 | 4 | SE. to NW | | 20 | W. D. Halsey, electrical engineer. | Duration of twenty seconds; writing at table, on second floor, frame house, on stone and brick foundations; several oscillations of whole house; a 9-inch pendulum swung NW. to SE.; the fourth shock was lightest. |
| | do | do | 40 41 | 73 56 | | | | | J. R. Healy | No one in the neighborhood of 144 South Fourth street felt the earthquake. |
| | do | do | 40 41 | 73 56 | | | | | O. J. Mauret | Shipping clerk, John street, near Baltic street, was asleep and felt no shock; neighbors in the street did not feel it. |
| | do | do | 40 41 | 73 56 | 3 | E. to W | 1 | | C. H. Moseley | Center of brick block, running E. and W., on second floor; table leaf swung and several persons nauseated; noticed by people sitting and standing. |
| | do | do | 40 41 | 73 56 | | | | | W. L. Stevens, professor physics, Packer Institute. | Was busy in study, at Packer Institute, a strong brick structure; felt no shock, nor did the janitor or his family; several in neighborhood noticed slight shock; chandelier swung in a house nearer East River. |
| | do | do | | | 2 | W. to E | | | New York Times, September 1, 1886. | In different parts of the city buildings were shaken, chandeliers rattled, and people frightened to the streets; very distinct at City Hall; the top of municipal building swayed softly and reporters grasped their desks to steady them; the interval was thirty-two minutes and duration of both about the same, the second shock being the most apparent. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**NEW YORK—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | m. | s. | | |
| | Brooklyn | Kings | 40 41 | 73 56 | 2 | | | | New York Tribune, September 1, 1886. | Felt in all parts of the city, but most evident on high ground of city and range of hills eastward. In top municipal building desks swayed W. to E., and on the second floor both shocks were noticed by Operator Gear, sitting in his office; he felt sick and thought it the heart disease: chandelier swung; the interval was thirty-two seconds, and duration of second shock two seconds. Felt distinctly on Hancock street, near Bedford avenue; direction was W. to E.; people rushed downstairs and assembled in the streets; many electric lights were extinguished. W. W. Heaton, of the U. S. Navy, was sitting in room on Columbia Heights, when he felt nervous; he arose, and the swaying continued; he immediately recognized its character. Mayor Whitney, at No. 10 Poplar street, felt chair, newspaper, and self shake; lamp on table shook. |
| | ...do | ...do | 40 41 | 73 56 | 2 | | | | New York Sun, September 1, 1886. | Distinctly felt on the sidewalk; people left their houses; the second shock was more apparent than the first; policemen on the bridge did not notice the shocks. |
| 10 | Buffalo | Erie | 42 53 | 78 54 | 2 | | | | Andrew Langdon, coal merchant. | House solid; light shock felt by the children; the bed shook so badly a 12-year-old child could not sleep; brass handles on furniture rattled. |
| | ...do | ...do | 42 53 | 78 54 | | | | | C. K. Remington | Awakened by sound as of a heavy wagon passing; window-sash shook slightly; child on spring mattress awakened by rattling of window. |
| | ...do | ...do | 42 53 | 78 54 | | | | | Buffalo Courier, September 2, 1886. | Some claim to have felt it; would not have been noticed here but for its presence elsewhere. |
| 11 | Buffalo Lights | ...do | 42 53 | 78 57 | | | | | J. M. Reed, keeper | Not felt in vicinity. |
| 12 | Castile | Wyoming | 42 38 | 78 05 | | | | | E. E. Howell | An intelligent lady at the water-cure says a number of the inmates felt it. |
| 13 | Catskill Mountains | | | | | | | | New York Times | |
| 14 | College Point | Queens | 40 47 | 73 50 | | | | | New York Tribune, September 2, 1886. | A vibration was noticeable. |
| 15 | Columbia County | | | | | | | | Albany Evening Journal. | Very generally felt. |
| 16 | Conewango Valley | Cattaraugus | 42 13 | 79 05 | 3 | | | | A lady | Shocks of decreasing intensity. Partially asleep; was aroused by a rumbling; shaking of house, followed by cracking and sudden jarrings. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**NEW YORK—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | | | | |
| 17 | Coxsackie | Greene | 42 22 | 73 44 | | | | | Albany Evening Journal, September 1, 1886. | Distinctly felt; building shaken and chairs rocked; some nauseated; no damage. |
| 18 | Coxsackie Light-house | ...do | 42 22 | 73 44 | | | | | F. L. Hoose, keeper | |
| 19 | Crown Point Light-station. | | 44 02 | 73 21 | | | | | L. F. Spaulding, keeper | Not felt. |
| 20 | Dale | Wyoming | 42 59 | 78 12 | | | | | H. K. Faunce, postmaster. | Do. |
| 21 | Dansville | Livingston | 42 34 | 77 43 | | | | | E. E. Howell | It is reported that shock was felt. |
| 22 | Delhi | Delaware | 42 17 | 74 53 | | | | | H. N. Buckley, postmaster. | Not felt. |
| 23 | Dunkirk Light-station | Chautauqua | 42 29 | 79 22 | | | | | R. Taggart, keeper | Not felt in vicinity. |
| 24 | East Albany | Rensselaer | 42 40 | 73 40 | | | | | Albany Evening Journal, September 1, 1886. | Shock distinctly felt. Lamps swayed and doors swung. |
| 25 | Esopus | Ulster | 41 48 | 73 56 | | | | | | At light-house very severe. |
| 26 | Fire Island Light-station. | | | | 3 | | | | S. R. Hubbard, keeper | Noise like thunder; tower swayed, and lens rattled, loudly; second heavier, and third heavier still; feared tower would fall; flame cut down to within half an inch of burner by the jar. |
| 27 | Flushing | Queens | 40 46 | 73 49 | | | | | New York Tribune, September 2, 1886. | Vibration was noticeable. |
| 28 | Fonda | Montgomery | 42 58 | 74 20 | | | | | F. L. Yates, teacher | House on hill in Mohawk Valley. To a party up-stairs lying down it seemed undulatory. Party sitting down-stairs saw statuette on piano shake and the bell above the chandelier sway; duration several seconds. |
| 29 | Fort Niagara Light-station. | Niagara | 43 15 | 79 03 | | | | | J. F. Taylor, keeper | Not felt. |
| 30 | Genesee Light-station | | | | | | | | A. J. Cary, keeper | Not felt in the vicinity. |
| 31 | Glens Falls | Warren | 43 18 | 73 34 | | | | 20 | Albany Evening Journal, September 1, 1886. | Ground rocked; and houses cracked like frost in midwinter. |
| 32 | Gloversville | Fulton | 43 04 | 74 17 | 3 | SE. to NW. | | 6 | | In bed second floor; third shock light. |
| 33 | Governor's Island | | 40 42 | 73 58 | 1 | | 4 | | Light-House Board | No noise; seemed like a horizontal tremor. |
| 34 | Gowanda | Cattaraugus | 42 28 | 78 57 | | S. by W. to N. by E. | | 10 | W. R. Smallwood, jeweler. | Undulatory. On first floor, small frame dwelling; felt movement, which caused dizziness; doors and pictures swung an inch; did not stop large pendulum clock. |
| 35 | Great West Bay Light-house. | Suffolk | 40 52 | 72 31 | | | | | W. H. Squires, keeper | Not felt. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**NEW YORK—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | m. | s. | | |
| 36 | Greenbush | Albany | 42 40 | 73 40 | | | | | Albany Evening Journal, September 1, 1886. | Lamps swayed and doors swung; shock distinctly felt. |
| 37 | Green Island | Lake George | 43 33 | 73 44 | | | 1 | | Dr. D. T. Willard | |
| 38 | Green Post | Suffolk | 41 06 | 72 22 | | | | | | |
| 39 | Harlem | New York | 40 48 | 73 56 | | | | | New York Herald | |
| 40 | Hicksville | Queens | 40 46 | 73 31 | 1 | | | | W. C. Miller, postmaster. | Slight; no noise. |
| 41 | Hoosick Falls | Rensselaer | 42 53 | 73 09 | 1 | N. to S. | | | H. M. Howe. | Noticed only under most favorable circumstances; five in village of 4,000 felt it; one party heard pitcher and basin rattle; no noise; duration variously estimated from two to thirty seconds. |
| 42 | Hudson | Columbia | 42 15 | 73 43 | 2 | E. to W. | | 30 and 10 | Associated Press, September 1, 1886. | Buildings creaked and sleepers awakened; interval sixteen minutes; E. to W., and very perceptible; pictures shaken on walls; no damage; many severely frightened. |
| 43 | Ithaca | Tompkins | 42 27 | 76 29 | | | | | New York Tribune, September 6, 1886. | Regulator on west wall D., L. & W. ticket office stopped. |
| | ....do | ....do | 42 27 | 76 29 | | E. to W. | | | Signal Service observer. | Regulator stopped; lasted several seconds. |
| 44 | Jamestown | Chautauqua | 42 06 | 79 15 | | | | 20 | Associated Press, September 1, 1886. | "Town severely shaken;" buildings shaken and people rushed into the streets; some made seasick. |
| | ....do | ....do | 42 06 | 79 15 | | | | 20 | Florida Times-Union, September 1, 1886. | "Severely shaken;" large buildings shaken and people rushed into the streets; chairs rocked and chandeliers vibrated; several nauseated by the undulations. |
| | ....do | ....do | 42 06 | 79 15 | 1 | | | | New York World, September 1, 1886. | Distinct shock; several windows broken and buildings vibrated for several seconds. |
| 45 | Kingston | Uls ter | 41 54 | 73 59 | 1 | | | | New York Tribune, September 2, 1886. | Lamps swung; water splashed from pitchers; clocks stopped; mirrors cracked, and dishes thrown from shelves; one lady dizzy, and another claims she was thrown out of bed; keeper says light-house swayed 6 inches; some felt shock at 2 p. m. |
| 46 | Lake Placid | Essex | 44 18 | 73 55 | 1 | | | | B. W. Frazier | Slight, but felt distinctly by several in hotel; oil oscillated in lamp; lasted a few seconds. |
| 47 | Long Island City | Queens | 40 45 | 73 57 | | | | | New York Tribune, September 2, 1886. | Distinctly felt at court-house and jail; ornaments on mantel in sheriff's room rattled. |
| 48 | Lyons | Wayne | 43 04 | 76 58 | | | | | M. A. Veeder | |
| 49 | Montauk Point Light-station. | Suffolk | 41 04 | 71 52 | | | | | J. G. Scott, keeper | Not felt. |

*Report of earthquake observations, earthquake of August 31, 1886*—Continued.

**NEW YORK—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | *m.* | *s.* | | |
| 50 | Monticello | Sullivan | 41 38 | 74 40 | | | | | R. B. Towner, deputy postmaster. | Not felt. |
| 51 | Montrose | Westchester | 41 15 | 73 53 | 2 | | | 20 | Miss M. Kruger | Each shock lasted ten seconds; interval thirty seconds; peculiar atmospheric effect after sundown; was awakened on second story; servant in upper story awakened and considerably frightened by violent shaking of bed; caused dizziness. |
| 52 | Narrowsburgh | Sullivan | 41 34 | 75 02 | | | | | K. B. Larison | Slight rocking of bed upon which I was lying, causing momentary dizziness. |
| 53 | New Brighton | Richmond | 40 38 | 74 04 | | | | | H. Wilcox | Not felt by people walking. |
| 54 | Newburgh | Orange | 41 30 | 74 00 | | | | | | Not felt. |
| 55 | Newtown | Queens | 40 45 | 73 52 | | | | | New York Tribune, September 2, 1886. | A vibration noticeable. |
| 56 | New York | | | | | | | | | See Chapter V. |
| 57 | North Salem | Westchester | 41 20 | 73 30 | | | | | Edward Hunt | Thought heard window-weight tapping against the casing. |
| 58 | Northville | Fulton | | | | | | | Albany Evening Journal, September 1, 1886. | Severe shock, accompanied by rumbling. |
| 59 | Oak Orchard Light-station. | Orleans | 43 22 | 78 14 | | | | | J. R. Kelly, keeper | Not felt. |
| 60 | Oswego | Oswego | 43 27 | 76 26 | | | | | J. A. Berry, postmaster | Do. |
| 61 | Oswego Lights | ....do | 43 27 | 76 30 | | | | | John Budds, keeper | Do. |
| 62 | Owego | Tioga | 42 06 | 76 15 | | | | | E. P. Clark, electrician | Conditions for observation favorable; not felt; made careful inquiries of others. |
| 63 | Peekskill on Hudson | Westchester | 41 18 | 73 55 | | | | | Dr. J. N. Tilden, A. M. | Conditions for observation favorable; made careful inquiries of others; not felt. |
| 64 | Penn Yan | Yates | 42 41 | 77 02 | 1 | | | | B. H. Wright | "Could scarcely be classed as very light, but 6 miles west; chandeliers, mirrors, desks, etc., were moved; not felt on intervening hills." |
| 65 | Plattsburgh Light-station. | Clinton | 44 41 | 73 24 | | | | | M. Bully, keeper | Not felt. |
| 66 | Poughkeepsie | Dutchess | 41 42 | 73 53 | 1 | | | | New York World, September 2, 1886. | Felt only in upper stories. |
| 67 | Purdy's | Orange | 41 34 | 74 27 | | | | | Miss R. Tompkins | Felt by several; lady thought dog was under bed. |
| 68 | Rochester | Monroe | 49 09 | 77 38 | 2 | N. to S. | | | Mrs. G. H. Perkins | Awake, in bed, front room, second story of hotel, on beach of Lake Ontario; shocks light but distinct; a rumbling sound during or a little after the shaking. |
| | .....do | ....do | 49 09 | 77 38 | | | | | E. E. Howell | Not felt; negative evidence nearly conclusive. |
| 69 | Rondout | Ulster | 41 54 | 73 57 | 3 | | | 30 | Boston Daily Globe | Three tidal waves on the Hudson. |
| 70 | Sackett's Harbor Light-station. | Jefferson | 43 56 | 76 08 | | | | | H. G. Nollway, keeper | Not felt in vicinity. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**NEW YORK—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | *m.* | *s.* | | |
| 71 | Saratoga Springs | Saratoga | 43 04 | 73 47 | | | | 30 to 60 | H. J. Horr | Sitting on sofa, shoulder against the wall, second story of three-story house; felt strong lateral motion; desk shaken; small object with suspension a foot long swung an inch or two. |
| 72 | Schenectady | Schenectady | 42 49 | 73 56 | 2 | | | | New York Tribune, September 2, 1886. | Many made sick for two or three hours. |
| | do | do | 42 49 | 73 56 | 2 | | | | New York Journal of Commerce. | |
| 73 | Shandaken | Ulster | 42 06 | 74 21 | | | | | | "Rattled windows." |
| 74 | Split Rock Lighthouse. | Essex | 44 16 | 73 15 | | | | | F. J. Sheldon, keeper | Not felt. |
| 75 | Stony Point Light-station. | Rockland | | | | | | | N. Smith, keeper | Do. |
| 76 | Stuyvesant | Columbia | 42 22 | 73 46 | 2 | | | | F. Peters, journalist | Rumbling noise; first shock most severe and lasted thirty seconds; interval, fifteen minutes; second lasted twelve seconds; bed shook; pendulum clock stopped; house trembled; no damage. |
| 77 | Troy | Rensselaer | 42 43 | 73 41 | | | | | Albany Evening Journal, September 1, 1886. | |
| 78 | Greene and Ulster counties. | | | | | | | | New York Times | Some localities people alarmed. |
| 79 | Utica | Oneida | 43 06 | 75 14 | 1 | | | | C. W. Darling | Reliable party felt shock; felt her chair sway under her; recognized it as an earthquake. |
| 80 | Walden | Orange | 41 33 | 74 10 | | | | | New York Times | |
| 81 | Warsaw | Wyoming | 42 44 | 78 09 | 1 | | | | New York World, September 1, 1886. | People "badly scared;" rushed from houses. |
| | do | do | 42 44 | 78 09 | | | | | H. K. Faunce | Facts obtained from others. |
| | do | do | 42 44 | 78 09 | | | | | E. E. Howell, of Rochester. | Paper reports "felt at Warsaw." |
| 82 | Warwick | Orange | 41 17 | 74 20 | | | | | Rev. G. W. Tinlaw | "Peculiar electrical condition of the clouds." Busy in study when my wife said: "What noise is that?" It was an indistinct rumbling, lasted a few seconds. |
| 83 | Washingtonville | do | 41 17 | 74 20 | | | | | New York Times | |
| 84 | Waterford | Saratoga | 42 48 | 73 37 | | | | | J. C. Platt, civil engineer. | Conditions for observation favorable; inquiries made; not felt. |
| 85 | Watkins | Schuyler | 42 23 | 76 52 | | | | | J. J. Van Allen, attorney. | Conditions for observation very favorable; not felt. |
| 86 | Woodstock | Ulster | | | | | | | New York Times | "Shocks very loud and vibrations very noticeable." |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**NORTH CAROLINA.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | *m.* | *s.* | | |
| 1 | Abbottsburgh | Bladen | 34 32 | 78 47 | 6 | | 2 | | A. C. Holston | Very forcible; general consternation; some chimneys overthrown or cracked; little damage done; loud roaring noise. |
| 2 | Albemarle | Stanly | 35 19 | 80 07 | 8 | | 5 | | R. E. Walker | Violent shocks, overthrowing light objects, causing great alarm. |
| 3 | Altamaha | Alamance | | | 3 | | | | A. T. Smith | Great heavy noise, like a freight train or the roar of a great fire; the earth shook and trembled greatly. |
| 4 | Ansonville | Anson | 34 55 | 80 06 | 4 | | | | R. E. Walker | Great commotion among both whites and negroes; some walls cracked. |
| 5 | Ashborough | Randolph | 35 43 | 79 43 | | | | | Wilmington paper | Severe earthquake; court-house bell rang; whole town terribly frightened; no serious damage. |
| 6 | Asheville | Buncombe | 35 40 | 82 26 | 4 | NW | 1 | 30 | Associated Press | Loud rumbling noise; houses violently shaken and the inhabitants all left them and fled into the streets; bells were rung, pictures were thrown from walls, and lamps overturned. |
| 7 | Bakersville | Mitchell | 36 01 | 82 05 | 3 | | | 15 | J. H. Green | Intensity best described by six or seven. |
| 8 | Bear Poplar | Rowan | 35 42 | 80 32 | | | | | J. W. Miller | Loud sound, like a heavy freight train; the earth "bumped" and quivered, causing his knees to feel shaky. |
| 9 | Beaufort | Carteret | 34 45 | 76 37 | 17 | | | | Associated Press | The town thrown into a state of terror and excitement; tops of chimneys shaken off; clocks stopped; mirrors and pictures thrown from walls; people left their houses and many staid in the streets all night; church bells rung. |
| 10 | Black Mountain | Buncombe | | | | | | | do | The earthquake phenomena reported to be startling; loud and prolonged rumblings; rocks detached and rolled down into the valleys. |
| 11 | Body's Island Light-house. | | | | 2 | | 2 | | P. G. Gallup | Watch-room door thrown open on north side of the room; found difficulty in walking. |
| 12 | Boone | Watauga | 36 13 | 81 36 | 2 | | | | D. B. Dougherty | Accompanied by rumbling sound; No. 6 best describes the intensity. |
| 13 | Brinkley's | Brunswick | 34 17 | 78 17 | 6 | | | | A. C. Holston | Houses violently shaken, chimneys overthrown, and plastering thrown down. |
| 14 | Buena Vista | Duplin | 34 56 | 77 47 | 3 | | | | F. E. Morrison | Severe shocks; no damage. |
| 15 | Burgaw | Pender | 34 31 | 77 56 | 4 | | | | S. S. Pearson | Very strong, but probably less so than at Wilmington. |
| 16 | Cape Fear | | | | | | | | J. H. Dosher | Light-house. |
| 17 | Cape Hatteras | | | | | | | | P. O. Buxton | Do. |
| 18 | Cape Lookout | | | | | | | | D. Rumley | Light-house; low rumbling, with undulatory movement; clock stopped. |

*Report of earthquake observations, earthquake of August 31, 1886*—Continued.

**NORTH CAROLINA—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | m. | s. | | |
| 19 | Carthage | Moore | 35 23 | 79 24 | | | | | T. Chalmers | Very strong; alarming everybody. |
| 20 | Cary | Wake | | | 3 | | | | J. B. Munn | Houses violently rocked; loud roaring sound. |
| 21 | Chapel Hill | Orange | 35 53 | 79 00 | 3 | | | | New York Times | Several shocks felt, decreasing in intensity to a mere quiver. |
| 22 | Charlotte | Mecklenburgh | 35 14 | 80 44 | 4 | | | | ......do | Several chimneys demolished; people rushed from their houses; great excitement prevailed; lamps overturned; church bells rung; many people camped in the open air. |
| 23 | China Grove | Rowan | 35 36 | 80 30 | 4 | | | | W. E. Morgan | No. 7 best describes it. |
| 24 | Clayton | Johnston | 35 39 | 78 27 | 6 | | | | G. Cosgrove | No. 7 or 8 best describes it. |
| 25 | Clinton | Sampson | 35 04 | 78 16 | | | | | F. Williston | Houses forcibly shaken; no damage of any importance; loud roaring sound. |
| 26 | Concord | Cabarrus | 35 26 | 80 30 | | | | | M. Donaldson | Forcible shock, creating great alarm; some chimneys cracked. |
| 27 | Covington | Richmond | 35 03 | 79 41 | | | | | Wilmington Star | Bricks shaken from several chimneys; women fainted with alarm. |
| 28 | Currituck | Currituck | 36 25 | 76 04 | 3 | | | 10 | A. J. Simpson | Light-house tower swayed; lens stopped revolving; motion like a ship in a seaway; walls of tower cracked. |
| 29 | Cypress Creek | Bladen | 34 45 | 78 26 | 5 | | | | A. C. Holston | Similar to Abbottsburgh. |
| 30 | Dallas | Gaston | 35 17 | 81 06 | 3 | | 1 | 30 | E. Parsons | Bricks thrown from half a dozen chimneys. |
| 31 | Durham | Orange | 36 01 | 78 52 | | | | | Associated Press | Caused much alarm, but no damage. |
| 32 | Edenton | Chowan | 36 05 | 76 34 | | | | | G. Farquhar | A very strong shock, followed by lighter ones; much alarm felt. |
| 33 | Elizabeth City | Pasquotank | 36 19 | 76 13 | | | | | N. Purman | No. 5 or 6 will describe it. |
| 34 | Elizabethtown | Bladen | 34 31 | 78 30 | | | | | A. C. Holston | Similar to Abbottsburgh. |
| 35 | Enfield | Halifax | 36 10 | 77 43 | 3 | | | 20 | J. Goodrich | Noise like distant thunder, followed by violent vibrations. |
| 36 | Fair Bluff | Columbus | 34 17 | 79 00 | | | | | A. C. Holston | Similar to Abbottsburgh, perhaps a little less violent. |
| 37 | Fairfield | Hyde | 35 35 | 76 12 | | | | | F. H. Corbin | No. 7 about describes it. |
| 38 | Faison's Depot | Duplin | 35 08 | 78 04 | | | | | C. C. Malley | Similar to Magnolia. |
| 39 | Fayetteville | Cumberland | 35 05 | 78 51 | 4 | | | | United Press | The first shock was very severe; ringing bells and overthrowing chimney tops; the fright and excitement were unparalleled; people ran through the streets praying and screaming. |
| 40 | Flat Rock | Henderson | 35 17 | 82 21 | 4 | | 2 | | C. C. Pinckney | Preceded by a deep subterranean sound; pictures were moved; doors and windows rattled; cracks in walls and ceilings. |
| 41 | Flemington | Columbus | 34 16 | 78 34 | | | | | G. N. Peters | Houses badly shaken up; glass broken; some chimneys cracked. |
| 42 | Fremont | Wayne | 35 33 | 77 55 | | | | | A. R. Newton | No. 7 best describes it. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**NORTH CAROLINA Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | | | | |
| 43 | Gold Hill | Rowan | 35 33 | 80 20 | | | | | L. Hawkins | Pictures thrown from walls; plastering dislodged. |
| 44 | Goldsborough | Wayne | 35 20 | 77 56 | 4 | | | 50 | J. M. Hillyer | First shock most violent; church tower cracked; in some houses books thrown from shelves and mantels; sensation like that of a ship at sea, the timbers creaking and groaning. |
| 45 | Gravel Hill | Bladen | 34 42 | 78 23 | | | | | A. C. Holston | Similar to Abbottsburgh. |
| 46 | Greensborough | Guilford | 36 03 | 79 44 | 5 | | | | Associated Press | A series of violent shocks, rocking houses until they seemed about to fall; the greatest consternation among the people. |
| 47 | Greenville | Pitt | 35 36 | 77 23 | | | | | do | People startled by the shocks and thrown into the greatest alarm. |
| 48 | Harrington | Harnett | 35 25 | 79 00 | | | | | H. L. Pender | Several shocks; No. 7 describes the heaviest. |
| 49 | Hatteras | Dare | 35 12 | 75 52 | 1 | | | | | Shock very moderate. |
| 50 | Henderson | Granville | 36 18 | 78 24 | | | | | Associated Press | As forcible as in Raleigh. |
| 51 | Hendersonville | Henderson | 35 20 | 82 22 | 3 | | 4 | | S. N. Cone | Was awakened by the shaking of bed and by the heavy shaking of the windows. |
| 52 | Hickory | Catawba | 35 50 | 81 23 | | | | | J. J. Allen | Houses shaken; plastering and pictures thrown from the walls. |
| 53 | Highlands | Macon | 35 19 | 83 17 | | | 2 | | Charleston News | Low rumbling noise. |
| 54 | Hillsborough | Orange | 36 03 | 79 04 | | | | | Associated Press | As strong as at Raleigh. |
| 55 | Holly Bush | Cleveland | 35 25 | 81 36 | | | | | J. M. Hall | No. 7 describes it. |
| 56 | Hope Mills | Cumberland | 35 04 | 78 52 | 3 | | | | B. B. Cassidy | Shocks most alarming, especially the first one; walls cracked; No. 8 perhaps describes it most nearly. |
| 57 | Huntersville | Mecklenburgh | 35 27 | 80 47 | 4 | | 5 | | W. Bollman | Lasted nearly five minutes; No. 8 seems to describe it. |
| 58 | Huntley | Sampson | 35 08 | 78 30 | | | | | J. Slingluff | No. 6 or 7 describes it. |
| 59 | Idaho | Cumberland | 35 05 | 78 48 | 3 | | | | J. Gross | A severe shaking up of everything; some houses considerably injured. |
| 60 | Jacksonville | Onslow | 34 45 | 77 22 | | | | | P. Callan | A very bad shake. |
| 61 | Jonesborough | Moore | 35 26 | 79 10 | | | | | Associated Press | People almost in a panic; ground rolled in waves. |
| 62 | Kelly's Cove | Bladen | | | 4 | | | | H. S. Jones | Plastering shaken down and houses severely strained. |
| 63 | Kenansville | Duplin | 34 54 | 77 55 | | | | | W. Porter | No. 7 seems to describe it. |
| 64 | King's Mountain | Cleveland | 35 12 | 81 17 | 3 | | | | B. A. Wallace | Violent undulatory motion and quaking, shaking houses badly and throwing loose articles about and causing great alarm. |
| 65 | Kinston | Lenoir | 35 16 | 77 32 | | | | | Associated Press | The place was much shaken up and the people left their houses in fright. |
| 66 | Kyle's Landing | Cumberland | 35 13 | 78 41 | 6 | | | | H. E. Woodley | It seems as if No. 8 would describe it. |
| 67 | La Grange | Lenoir | 35 20 | 77 43 | | | | | W. D. Crump | No. 7 seems to describe it. |
| 68 | Laurel Point | | | | 3 | | | 30 | W. J. Harris | Light-house. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**NORTH CAROLINA—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | | | | |
| 69 | Laurinburgh | Richmond | 34 48 | 78 26 | 6 | | | | A. Tischbein | Dull roaring sound; buildings severely shaken and plastering brought down in many houses. |
| 70 | Lilly | Camden | 36 30 | 76 18 | | | | | Richmond Whig | People awakened by a terrible shaking of the earth; the houses and contents shook as if in a terrific storm. |
| 71 | Lincolnton | Lincoln | 35 29 | 81 12 | | | | | T. B. Conway | A very forcible and alarming shake; glass broken and chimneys cracked; light objects overthrown. |
| 72 | Long Creek | Pender | 34 27 | 78 00 | 3 | | | | Wilmington Star | Fearful rumbling noise. People fled in terror to the streets; floor of house seemed to twist and shiver so that it was difficult to stand without support. |
| 73 | Lumberton | Robeson | 34 38 | 79 02 | | | | | do | A severe shock. |
| 74 | Magnolia | Duplin | 34 49 | 78 12 | 3 | | | | C. E. Malley | Furniture moved; houses rocked violently; plastering cracked and shaken down; great alarm felt. |
| 75 | Masonborough | New Hanover | 34 08 | 77 51 | | | | | Wilmington Star | Similar to Wilmington; a bureau overturned in one house. |
| 76 | Monroe | Union | 34 58 | 80 35 | 5 | | | | T. Cartwright | Houses badly shaken; negroes panic-stricken; some walls cracked; no serious damage done. |
| 77 | New Berne | Craven | 35 08 | 77 02 | | | | | Richmond Whig | The shock was first felt as of a passing train, increasing in violence with a swaying sensation like the rolling of a ship, the whole continuing 30 seconds; persons in bed awakened and others highly excited. |
| 78 | Mount Olive | Wayne | 35 14 | 78 00 | | | | | S. O. Gladden | No. 7 describes it. |
| 79 | Mount Pleasant | Cabarrus | 35 25 | 80 21 | | | | | M. Donaldson | Similar to Concord. |
| 80 | New Supply | Brunswick | 34 00 | 78 22 | | | | | Wilmington Star | At first a sound like a running train, and as the sound came nearer the earth began to tremble and vibrate fearfully. Although buildings were rocked and creaked, no damage was done. |
| 81 | Oak Grove | Union | 35 08 | 80 28 | | | | | T. Cartwright | About the same as at Monroe. |
| 82 | Oxford | Granville | 36 21 | 78 34 | 4 | | 1 | 30 | Richmond Whig | Shock quite severe; sufficient to displace crockery in the stores. There was great excitement, and a large part of the people were thoroughly frightened. |
| 83 | Pineville | Mecklenburgh | 35 09 | 80 50 | | | | | F. Sohmer | Very powerful and alarming shocks. |
| 84 | Raleigh | Wake | 35 46 | 78 37 | 5 | | 5 | | Associated Press | Rang church-bells; threw down plastering; cracked some walls; overthrew chimneys; created panic among negroes. |
| 85 | Richlands | Onslow | 34 52 | 77 32 | 4 | | | 35 | Wilmington Star | Severe shock, lasting 35 seconds, followed by three others; the streets of the village thronged with excited people. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**NORTH CAROLINA—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | | | | |
| 86 | Robbinsville | Graham | 35 20 | 83 51 | 5 | | 1 | | G. B. Walker | No. 7 about describes it. |
| 87 | Rockingham | Richmond | 34 55 | 79 43 | 6 | | | | Wilmington Star | The first shock shook down light objects and caused great fright among women and children. |
| 88 | Rutherfordton | Rutherford | 35 24 | 81 49 | | | | | A. L. Grayson | Numerous shocks. While walking, heard the sound; seemingly from northwest, like a train of cars; a few seconds later the shock came. |
| 89 | Salisbury | Rowan | 35 41 | 80 29 | 3 | | 1 | 30 | New York Tribune | All the people fled into the streets. |
| 90 | Sanford | Moore | 35 36 | 79 11 | | | | | T. Chalmers | Very strong. No. 7 describes it. |
| 91 | Selma | Johnston | 35 33 | 78 16 | | | | | E. Patterson | About No. 7. |
| 92 | Shallotte | Brunswick | 34 04 | 78 31 | | | | | F. Kuhn | Abont No. 6 or 7. |
| 93 | Smithville | do | 33 56 | 78 00 | 2 | | 1 | | R. Chaffee | Sound first heard like wind, or freight train crossing a bridge, followed by breaking glass in surrounding houses; then a terrible commotion of the earth and lower floor of the house; the piazza seemed to rise and fall as if a wave passed under it. |
| 94 | Soapstone | Randolph | 35 48 | 79 35 | | | | | H. L. Kinney | About No. 7. |
| 95 | Statesville | Iredell | 35 47 | 80 49 | | | | | J. R. Johnston | A very strong shock, creating much alarm. |
| 96 | Trenton | Jones | 35 05 | 77 20 | | | | | J. Horner | About No. 7. |
| 97 | Troy | Montgomery | 35 26 | 79 48 | | | 3 | | Wilmington Star | The vibration was preceded by a heavy roaring sound; bells rang; windows rattled; and bricks were shaken from chimneys. Persons in the street felt it very severely. |
| 98 | Wadesborongh | Anson | 34 55 | 79 56 | 6 | | 2 | | J. Camp | A very violent shock, lasting two or three minutes, followed by five others. It seemed as if houses must fall. No. 8 seems to describe it. |
| 99 | Wadeville | Montgomery | 35 21 | 78 53 | | | 2 | | Wilmington Star | Heavy rumbling noise. It seemed as though the first shock would wreck houses. |
| 100 | Waynesville | Haywood | 35 33 | 82 51 | | | | | New York Herald | A number of chimneys shaken down. |
| 101 | Weaverville | Buncombe | 35 41 | 82 26 | 3 | | | | New York Sun | Three violent shocks. |
| 102 | Weldon | Halifax | 36 24 | 77 37 | 4 | | | | New York Herald | A violent shock, followed by three lighter ones. |
| 103 | Whiteville | Colnmbus | 34 17 | 78 43 | | | | | A. C. Holston | Similar to Brinkley. |
| 104 | Wilmington | New Hanover | 34 14 | 75 55 | 3 | | | 36 | Wilmington Star | Severe; people greatly alarmed and rushed from their houses. Shocks accompanied by a prolonged rumbling; river seemed to be violently agitated and washed against its banks as if by a storm; plastering dislodged in houses and bricks shaken from chimneys and from the walls of houses in process of erection. |
| 105 | Winston | Forsyth | 36 08 | 80 09 | 5 | N. to S | 1 | 30 | W. A. Whitaker | No. 7 describes it. |
| 106 | Wolfsville | Union | 34 54 | 80 42 | 4 | | | | T. Cartwright | Similar to Monroe. |
| 107 | Woodleaf | Rowan | 35 45 | 80 30 | 4 | | | | S. Summers | No. 7 describes it. |

*Report of earthquake observations, earthquake of August 31, 1886*—Continued.

**OHIO.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | *m.* | *s.* | | |
| 1 | Akron | Summit | 41 05 | 81 30 | | | | | Prof. C. S. Howe | In house; did not feel shock. |
| 2 | Ashtabula Light-station. | Ashtabula | 41 52 | 80 47 | 1 | SW. to NE | | 2 | | Very light; was reading in the beacon; calm and chilly. |
| 3 | Athens | Athens | 39 23 | 82 10 | | | | | Cincinnati Enquirer, September 1, 1886. | First shock lasted over a minute and shook houses, rattled windows, broke household articles, and awoke sleepers; people greatly alarmed. |
| 4 | Batavia | Clermont | 39 09 | 84 12 | | | | | Cincinnati Enquirer, September 1, 1886. | Distinctly felt. |
| 5 | Beaver | Pike | 39 06 | 82 52 | 2 | S. to N | | | Rev. J. M. Grether | Duration over half a minute. |
| 6 | Bellaire | Belmont | 40 04 | 80 51 | | | | | Wheeling Intelligencer, September 1, 1886. | Severely felt. |
| | do | do | 40 04 | 80 51 | | | | | Wheeling Register, September 2, 1886. | About one-third of the people felt shock. |
| 7 | Bridgeport | do | | | | | | | Wheeling Intelligencer, September 1, 1886. | Severely felt. |
| 8 | Buchtel | Athens | 39 32 | 82 15 | | | | | Cincinnati Commercial Gazette, September 1, 1886. | Reports say shock was felt. |
| | do | do | 39 32 | 82 15 | 2 | | 2 | | J. Manrer | Total duration two minutes. |
| 9 | Calais | Monroe | 39 55 | 81 24 | | W. to E | | | C. L. Eberly, postmaster. | On second floor; building shook twice; wife on first floor, much frightened. In one house plastering fell. Most severe in the lowlands. |
| 10 | Caldwell | Noble | 39 48 | 81 36 | 1 | | | 2 or 3 | D. L. Spriggs, postmaster. | Very light. At residence, upstairs. |
| 11 | Canton | Stark | 40 49 | 81 34 | 4 | | | | Cincinnati Commercial Gazette, September 1, 1886. | Unusually severe. Business buildings creaked; people rushed to the streets; guests in hotels awakened by flying open of doors and the shaking of beds and windows,. Several vibrations; best observers think four. |
| | do | do | 40 49 | 81 34 | | | | | N. C. Schaeffer | In Canton, and felt no shock. A band playing in upper story was frightened down stairs by creaking of house and swinging of chandeliers. |
| | do | do | 40 49 | 81 34 | 4 | N. to S | | | New York Sun, September 2, 1886. | |
| 12 | Chagrin Falls | Cuyahoga | 41 34 | 81 27 | | | | | J. J. Stranahan, proprietor "Exponent." | Diligent inquiry made. Not felt in town or vicinity. Country hilly, principal ranges running north and south. |
| 13 | Chillicothe | Ross | 39 26 | 83 01 | 2 | W. to E | | | Student in grammar school. | First floor, lying down; furniture moved slightly; some clocks stopped and some people frightened; durations, five and twenty seconds, respectively. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**OHIO—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | | | | |
| 14 | Cincinnati | Hamilton | 39 09 | 84 30 | | | | | Associated Press | Most severe on high ground, in upper stories of tall buildings. Considerable alarm in hotels and theaters. Noticed by few on the streets, not generally throughout the city; buildings swayed violently, dishes thrown from shelves and light articles from mantels; chandeliers agitated and people generally frightened; many seized with dizziness. Felt very decidedly in composing rooms of Commercial Gazette; a general rush from the rooms was made by the employés, some leaving by the windows; a slight tremor felt on first floor by those sitting; duration about one-half a minute, and direction probably E. to W. |
| | do | do | 39 09 | 84 30 | 2 | NW. to SE. | | | Cincinnati Commercial Gazette, September, 1886. | In the Gazette editorial rooms, workers at their desks swayed in their chairs, chandeliers vibrated, and a sickly sensation overcame many. Direction, according to many, NW. to SE.; duration about ten seconds, and fifteen minutes later a second lighter and shorter shock. On the top floor a panic seemed imminent. Shock very generally felt, invariably causing alarm in upper stories. |
| | do | do | 39 09 | 84 30 | | | | | Cincinnati Times-Star, September 1, 1886. | A great majority felt the shock; direction first, E. to W. then N. to S.; decidedly undulatory; no rumbling. In a four-story block, doors shook, windows rattled, building swayed N. to S., and the inmates, thoroughly alarmed, rushed to the streets, and many hesitated to return. |
| | do | do | 39 09 | 84 30 | | N. to S. | | | G. E. Walton, M. D., author "Mineral Springs of the United States." | First floor, three-story brick building; violent swinging of heavy chandeliers from N. to S.; sensation to one standing, a gentle undulation. |
| | do | do | 39 09 | 84 30 | | E. to W. | | | William Kirk | Was awakened by shaking of bed. |
| 15 | Circleville | Pickaway | 39 39 | 83 00 | | | | | Cincinnati Enquirer, September 1, 1886. | Violent shaking; larger buildings rocked perceptibly, and a number of persons in upper stories left their rooms. |
| 16 | Cleveland | Cuyahoga | 41 31 | 81 46 | 3 | | 1 | | Associated Press | Very severe shocks; generally felt throughout city; houses shook, lamps swayed, clocks stopped, and light movables toppled. Occupants of hotels and theaters rushed frantically to the streets. Those in bed fled from rooms undressed; considerable excitement; no damage. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**OHIO—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | | | | |
| 16 | Cleveland | Cuyahoga | 41 31 | 81 46 | 3 | E. to W. | | 15 | New York Times, September 1, 1886. | High building swayed; people rushed to the streets; theaters emptied and meetings broken up; a very general feeling of nausea; not noticed by many on ground floor. At Opera House and Academy of Music a stampede was made for the exits; chandeliers and all suspended objects swung violently. Generally felt throughout city. At the Doane the panic was frightful; plastering was shaken from walls and pictures fell down. The shock seemed most severe near the lake shore. |
| | do | do | 41 31 | 81 46 | | | | | Dr. E. Sterling | On first floor three-story brick house, first shock decided, second more severe. Wood-work creaked, furniture moved, and a new frame house, on filled-in earth, leaned 3 feet from perpendicular by settling of the earth. |
| | do | do | 41 31 | 81 46 | | | | | P. S. Cobb | Distinctly felt; of moderate intensity; swinging chandeliers, doors, pictures, etc. |
| | do | do | 41 31 | 81 46 | 2 | | | | Signal Service Observer. | |
| 17 | Cleveland Light-station. | do | 41 31 | 81 46 | 2 | E. to W. | | | G. H. Tower, keeper | Duration, a few seconds each; no noise; very plainly noticed in upper stories of buildings; chandeliers swung. Felt 1 mile back, but not on lake front or the water. Clay over shale and deep underlying rock. |
| 18 | Collinwood | do | 41 33 | 81 38 | | | | | P. L. Cobb | Duration, eight or ten seconds; no noise; intensity "very light;" felt by few persons. |
| 19 | Columbus | Franklin | 40 01 | 83 04 | | | | | Associated Press | Distinctly felt; most perceptible in large buildings; furniture moved, rocking-chairs set in motion, and chandeliers swung. Felt all over the city, accompanied by low, heavy rumbling in some cases. |
| | do | do | 40 01 | 83 04 | 2 | NW. to SE. | | 30 | Sergt. A. L. McCrae, Signal Service. | Shaking of building very marked; second shock severest, and accompanied by rumbling. |
| | do | do | 40 01 | 83 04 | 2 | N. to S. | | | H. R. Gill | On third floor very shaky building; cases rattled; telegraph wires vibrated; chandeliers swung. First shock N. to S., lasting about eighty seconds; second, E. to W., and shorter duration. |
| 20 | Coshocton | Coshocton | 40 18 | 81 55 | 2 | | | | New York Tribune, September 2, 1886. | |
| 21 | Crayon | Champaign | 40 14 | 83 52 | | | | | Cincinnati Enquirer, September 1, 1886. | People rushed wildly to the streets and many were nauseated; meetings were broken up. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**OHIO—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | *m.* | *s.* | | |
| 22 | Dayton | Montgomery | 39 46 | 84 12 | | | | 20 | Associated Press | Plainly felt in all sections of city. Most severe in high buildings; some buildings swayed an inch; some people left buildings. |
| | ...do | ...do | 39 46 | 84 12 | | N. to S. | | 30 | Chicago Inter Ocean, September 1, 1886. | Felt in all parts of city, and most perceptible in upper stories; chandeliers swung, tables and chairs moved, and many were made dizzy and nauseated. Hotels and printing offices hastily deserted. Shocks close together, of equal duration, and accompanied by a roaring. |
| 23 | Dennison | Tuscarawas | 40 24 | 81 25 | | | | | New York Sun | A meeting broke up in a panic. |
| 24 | Easton | Wayne | 40 58 | 81 48 | 4 | N. to S. | | | Savannah Morning News, September 2, 1886. | |
| 25 | Gallipolis | Gallia | 38 54 | 82 17 | 2 | | | | Cincinnati Enquirer, September 1, 1886. | Many awakened; dizziness and fright; a minute or two later a second and much lighter tremor. |
| 26 | Garrettsville | Portage | 41 17 | 81 10 | | | | | No name | Felt. |
| 27 | Germantown | Montgomery | | | | | | | Cincinnati Enquirer, September 4, 1888. | Very distinct shocks; buildings rocked undulatory. |
| 28 | Hamilton | Butler | 39 26 | 84 33 | | | | | New York Sun, September 2. | Hotels deserted and walls said to have swayed one and one half inches. |
| | ...do | ...do | 39 26 | 84 33 | | SE. to NW. | | | William Schlosser | In rocking-chair, second story; two jars, followed by an undulating motion of water in glass, SE. to NW.; pitcher in bowl rocked; clock stopped. |
| 29 | Hillsborough | Highland | 39 16 | 83 34 | 2 | | | | H. A. Pavey | Interval one and one-half minutes; duration first shock, one and one-half seconds; of second, one second. In light buggy, 10 miles N. of Hillsborough; underlying rock, blue limestone, 1,200 feet thick; buggy stationery; swayed a little; wheels rattled, etc.; buggy running at time of second shock. Atmosphere very clear, as shown by observation of Observatory, but many nights before and after very hazy. Mrs. A. B. Pavey was sitting in library, down-stairs, reading; house two-story brick; windows rattled, and in about one and one-fourth minutes a second and lighter shock rattled them again. |
| 30 | Ironton | Lawrence | 38 37 | 82 42 | 3 | | | | Cincinnati Enquirer, September 1, 1888. | Distinct shocks; bells rang, buildings swayed, and furniture moved; many left houses. |
| | ...do | ...do | 38 37 | 82 42 | 2 | | | | Cincinnati Times-Star, September 1, 1886. | Very severe shocks all over city and surrounding country. Windows shook, doors and church bells rang, and clocks stopped; quite a number left houses. |

*Report of earthquake observations, earthquake of August 31, 1886*—Continued.

**OHIO—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | m. | s. | | |
| 31 | Lancaster | Fairfield | 39 45 | 82 39 | | | 1 | | Associated Press | Violent earthquake; hundreds rushed to the streets; decorations shaken down and several chimneys toppled over. |
| | ......do | ....do | 39 45 | 82 39 | | | | | Louisville Commercial, September 1, 1886. | Telephone message says "shock threw down a chimney." |
| 32 | Leipsic | Putnam | 41 06 | 84 00 | 2 | | | | J. D. Haderman | Felt shock; in a few cases windows held up by friction only were lowered by the shock. |
| 33 | Lima | Allen | 40 45 | 84 07 | | | | | Cincinnati Enquirer. September 1, 1886. | Plainly felt in western part of city; duration, several seconds; pictures shaken from walls in several places; not generally recognized until next morning. |
| 34 | Lincoln | Gallia | 38 47 | 82 29 | 1 | S. to N | | 10 | M. M. Walter | Awakened by loud and distinct rumbling, which was followed by shock from the S. |
| 35 | Lockland | Hamilton | 39 16 | 84 25 | | ....do | | | Miami Valley News, September 9, 1886. | Clocks stopped; some people made dizzy; windows and lamps shaken; horizontally and undulatory. |
| 36 | Logan | Hocking | 39 36 | 82 28 | | | | | Cincinnati Enquirer, September 1, 1886. | Houses shaken and rocked, bricks knocked from chimney tops, and children badly frightened. |
| 37 | London | Madison | 39 55 | 83 29 | | NE. to SW | | | F. Webster, attorney | Second story, brick building; slight vibration of furniture and walls; hanging lamp swung an inch from E. to W.; several nauseated; not felt by majority of people. |
| 38 | Ludlow | Hamilton | 39 12 | 84 30 | 3 | | | | Cincinnati Times-Star, September 1, 1886. | Felt very perceptibly; windows rattled, door bells rang, lamps shook, and signs swung. |
| 39 | Linwood | ....do | 39 11 | 84 26 | | | | | ......do | Windows rattled and hanging articles swayed; many alarmed. |
| 40 | Mansfield | Richland | 40 47 | 82 34 | | | | | Associated Press | Slight shock; some alarm. |
| 41 | Marblehead Light-station. | | 41 32 | 82 46 | | | | | G. H. McGee, keeper | Not felt. |
| 42 | Marietta | Washington | 39 29 | 81 32 | 8 to 10 | | 30 to 40 | | C. J. Sheppard | Brick house moved; inmates frightened; door bells rung in various parts of town, and light articles moved. Animals in circus frightened and consternation in the audience. |
| 43 | Marion | Marion | 40 36 | 83 10 | 1 | | 1 or 2 | | B. Tristram, postmaster. | Very light; noticed by few; no noise. |
| 44 | Massillon | Stark | 40 49 | 81 31 | | | | | Associated Press | All the houses shaken; people left houses; great excitement. |
| 45 | Maumee Bay Range Lights. | | | | | | | | W. H. Jennings, keeper. | Not felt. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**OHIO—Continued.**

| No. | Locality. | County. | Latitude. ° ′ | Longitude. ° ′ | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| 46 | Millersburgh | Holmes | 40 33 | 81 57 | 1 | | | 60 | C. J. Voorhees | In second story, was awakened by swaying of house; floor swayed vertically; everything cracked, pictures swung, and plastering bulged out from N. wall; several ran out of houses. |
| 47 | Montpelier | Williams | 41 35 | 84 36 | | | | | L. A. Howard | Not felt within 20 miles. |
| 48 | Morrow | Warren | 39 24 | 84 08 | | | 2 | | Cincinnati Enquirer, September 1, 1886. | Distinctly felt by many. |
| 49 | Mount Vernon | Knox | 40 26 | 82 32 | 3 | E. to W. | | | ......do | Undulatory; shocks one or two seconds apart; chandeliers shook, windows rattled, and all movable object were affected; people ran ont of houses; felt slightly on the streets. |
| 50 | Murray City | | | | | | | | Cincinnati Commercial Gazette, September 1, 1886. | Reports say shock was felt. |
| 51 | Nelsonville | Athens | 39 31 | 82 18 | | | | | ......do | Felt plainly; duration, several minutes; buildings shaken, inmates awakened, and frightened to the streets, where the excitement was intense. Most severe at Dew House and depot. Several street lamps went out. |
| 52 | New Amsterdam | | | | | | | | New York Herald, September 2, 1886. | |
| 53 | Newark | Licking | 40 06 | 82 29 | | NE. to SW. | | 5 or 10 | F. Webster, attorney | Brick block, second story; hotel rocked and ladies left rooms. |
| | ......do | ....do | 40 06 | 82 29 | | | | | T. G. Thoston, attorney. | Undulatory; generally felt; light objects moved, etc. |
| 54 | New Comerstown | Tuscarawas | 40 19 | 81 40 | | | | | New York Tribune, September 2, 1886. | Glassware rattled distinctly. |
| 55 | New Philadelphia | ....do | 40 31 | 81 29 | | N. to S. | | | Cincinnati Enquirer, September 1, 1886. | Severe earthquake, lasting one-half to three-quarters of a minute. Some ran out of houses; clocks stopped; furniture and crockery rattled. |
| 56 | New Richmond | Clermont | 39 02 | 84 14 | | | | | ......do | Most severe; crockery and mantel ornaments thrown down; no damage of consequence. |
| 57 | Oberlin | Lorain | 41 17 | 82 13 | | | | | Prof. A. A. Wright | Duration, a few seconds. In second story, gentle rocking two or three times; not generally noticed. Facts obtained from Miss Wright and Mrs Arnold. |
| 58 | Portsmouth | Scioto | 38 49 | 83 04 | 2 | | | | Cincinnati Times-Star, September 1, 1886. | Interval, ten minutes; entire city trembled; people badly frightened. |
| | ......do | ....do | 38 49 | 83 04 | | | | 40 | Signal Service observer | Apparent lull at end of twenty-five seconds; low rumbling reported; soft alluvial river bottom. |
| 59 | Ripley | Brown | 38 50 | 83 50 | 3 | | | | Cincinnati Times-Star, September 1, 1886. | Very severe; people fled to the streets; third shock very light. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**OHIO—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | *m.* | *s.* | | |
| 60 | Rockland | Washington | 39 20 | 81 43 | | | | | T. O. McTaggart, postmaster. | Duration, about five minutes; no noise; temperature, 46°. |
| 61 | Steubenville | Jefferson | 40 23 | 86 43 | | | | | Cincinnati Enquirer, September 1, 1886. | Pictures thrown down; windows broken; door-bells rang; chandeliers swung 2 or 3 inches, and in one house plastering knocked from ceiling. |
| | do | do | 40 23 | 86 43 | | | | | Wheeling Register | Sharp shock. |
| 62 | Toledo | Lucas | 41 38 | 83 34 | | S. to N | 1 | | G. E. Pomeroy | Duration, nearly one minute; sitting in library; drop-light swung S. to N. about a foot; mirror on south wall struck quite hard against it; did not notice motion of frames on east and west wall; decidedly undulatory; some people nauseated. |
| 63 | Turtle Island | do | 41 44 | 83 23 | | | | | W. Haynes (light-house keeper). | Not felt; small island composed of sand, protected by piles and stone riprap. |
| 64 | Upper Sandusky | Wyandot | 40 51 | 83 19 | 2 | | | | Cincinnati Enquirer, September 1, 1886. | Shocks in quick succession; much alarm; people rushed from houses. |
| 65 | Van Wert | Van Wert | 40 53 | 84 33 | 1 | | | | New York Times, November 30, 1886. | Plainly felt. |
| 66 | Versailles | Darke | 40 14 | 84 30 | | N. to S | | | Cincinnati Enquirer, September 1, 1886. | Noticed distinctly by several persons in houses and on the streets. |
| 67 | Washington Court House. | Fayette | 39 35 | 83 29 | 2 | | | | do | Distinctly felt; several minutes' interval; first most severe and lasted one minute. |
| 68 | Waynesville | Warren | 39 33 | 84 05 | | | | | do | Distinctly felt by a number. |
| 69 | Wellsville | Columbiana | 40 38 | 80 43 | 2 | E. to W | | | G. W. Gellespie | Duration first shock, thirty seconds; light; heavy table shook; a trembling; chandeliers swung nearly E. to W.; duration second shock, ten or fifteen seconds. |
| 70 | Westerville | Franklin | 40 12 | 82 58 | 2 | SE. to NW | | | | No sound. |
| 71 | Willoughby | Lake | 41 40 | 81 27 | | | | | G. C. St. John | Not felt; careful inquiry made. |
| | do | do | 41 40 | 81 27 | | | | | | Very slight; hardly felt. |
| 72 | Wilmington | Clinton | 39 28 | 83 52 | | E. to W | | | Cincinnati Commercial Gazette, September 1, 1886. | Undulatory; duration, several seconds; particularly noticeable in second and third stories; chandeliers shook violently several minutes; many felt dizziness. |
| 73 | Woodsfield | Monroe | 39 49 | 81 14 | | | | | J. R. Morris, postmaster. | Shock was felt, but was asleep and can give no particulars. |
| 74 | Wooster | Wayne | 40 48 | 82 00 | | | | | S. Walker | A distinct tremor; peculiar behavior of horse and dog. |
| 75 | Wyoming | Hamilton | 39 16 | 84 26 | | | | | Cincinnati Times-Star, September 1, 1886. | Very severe shock; beds moved and pictures swung; loud rumbling; people much frightened. |

*Report of earthquake observations, earthquake of August 31, 1886*—Continued.

**OHIO—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | *m.* | *s.* | | |
| 76 | Zanesville | Muskingum | 40 00 | 82 04 | 2 | | | | Louisville Commercial, September 1, 1886. | Distinct shocks; chandeliers swung and dishes rattled; a meeting was broken up, and guests left rooms in hotels; people greatly frightened; no damage. |

**ONTARIO.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. *m.* | Duration. *s.* | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Belleville | | 44 08 | 77 23 | | | | | J. T. Bell | Not felt within 50 miles. |
| 2 | Guelph | | 43 33 | 80 15 | | | | | Prof. J. Hoyds Pantor | Not felt. |
| 3 | Hyacinthe | | 45 30 | 74 30 | | | | | Prof. C. P. Choquette | Not felt within 25 miles; soil, argillaceons, resting on Silurian schists. |
| 4 | London | | 43 00 | 81 14 | | | | | New York Herald and Sun. | |
| | ......do | | 43 00 | 81 14 | | | | | New York Tribune, September 2, 1886. | "Shock felt." |
| | ......do | | 43 00 | 81 14 | | | | 30 | Louisville Commercial. | Windows rattled and floors quivered; no damage. |
| 5 | Montreal | | 45 30 | 73 30 | | | | | J. M. Dawson | Not felt. |
| 6 | Ottawa | | 45 25 | 75 42 | | | | | G. M. Dawson | Do. |
| 7 | Petrolia | | 42 52 | 82 08 | 1 | | | | Chicago Herald, September 2, 1886. | Was felt. |
| | ......do | | 42 52 | 82 08 | 1 | | | | New York Herald, September 2, 1886. | Do. |
| 8 | Port Dover | | 42 49 | 80 14 | 1 | | | | Henry Morgan | After considerable inquiry found three ladies who felt shock; thought some one under beds; looking-glass swayed. The three lived in different parts of town. |
| 9 | Sarnia | | 42 59 | 82 23 | | | | | J. G. McCree | Lying on bed; felt oscillating; door on opposite side of room shook and creaked very distinctly; oil in lamp shook. |
| 10 | Sunshine Post-office | | | | | | | | George Hood | Not felt. |
| 11 | Toronto | | 43 39 | 79 22 | | | 4 | | Professor Carpmael | Magnetic needles set in motion by earth tremors. |
| | ......do | | 43 39 | 79 22 | | | | | Boston daily, September 2, 1886. | Distinctly felt in "outlying" parts of city; massive buildings shaken violently; three great waves on bay, small boats narrowly escaping being swamped. |
| 12 | Watford | | 42 57 | 81 53 | | | | | John White, assistant postmaster. | Not felt. (Letter written last of November.) |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**ONTARIO—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | m. | s. | | |
| 13 | Woodstock | | 43 08 | 80 48 | 1 | | | 10 or 12 | N. Wolverton | Wife of principal of Woodstock College alone, lying on bed; felt house sway like ship at sea; undulations shorter than of a small boat; no one else in town felt shock. |

**PENNSYLVANIA.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Altoona | Blair | 40 31 | 78 28 | 2 | | | 1 | W. T. Miller | At eastern foot of Alleghenies, surrounded by mountains to the north, south, and west; felt peculiar and very distinct rolling; undulatory; more roll than shock; no jar sufficient to rattle sash, glass, or loose articles; severest on high ground; a large number walking on street felt swaying, which caused them to stagger. |
| 2 | Beaver Falls | Beaver | 40 46 | 80 22 | | | | | Pittsburgh Dispatch, September 1, 1886. | "Felt distinctly;" most people in bed; they arose and rushed to the streets; thousands were in the street, many of them in night clothes; a meeting hastily adjourned. |
| 3 | Bellefonte | Centre | 40 55 | 77 50 | | | | | Centre Reporter | "Shocks were felt;" some got out of bed to find cause of disturbance. |
| 4 | Birdsborough | Berks | 40 16 | 75 48 | | | | | Harrisburg Daily Patriot, September 2, 1886. | Shock caused much excitement. |
| 5 | Boalsburgh | Centre | 40 46 | 77 50 | 3 | | | | Centre Reporter, September 8, 18:6. | "Severely shaken;" many badly frightened, thinking some one under bed; most severe in western part of town and in stone or brick houses; three distinct shocks and a rocking. |
| | ......do | ....do | 40 46 | 77 50 | 2 | | | | J. Simpson Africa | Duration first, thirty seconds; interval, ten minutes (through Prof. J. P. Lesley). |
| 6 | Bossardsville | Monroe | 40 57 | 75 18 | | N. to S. | | 30 | R. H. Clare | Fair observation; no noise; very light; undulatory; not generally felt. |
| 7 | Centre Hall | Centre | 40 50 | 77 44 | | | | 4 | Centre Reporter, September 8, 1886. | Brick house on solid bed of limestone; ready to retire; startled by singular rumbling as of very heavy wagon passing slowly; sound of a metallic nature; vibrations lasted upward of four seconds; after reading papers, "struck us" as an earthquake. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**PENNSYLVANIA—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | m. | s. | | |
| 8 | Fort Pitt Foundry, Hulton. | Allegheny | 40 24 | 80 10 | | | | | | |
| 9 | Franklin | Venango | 41 24 | 79 53 | | | | | D. D. Grant, postmaster. | After reading newspapers, a few remembered feeling shock slightly. |
| 10 | Harrisburg | Dauphin | 40 15 | 76 54 | | | | | E. H | Not mentioned by Harrisburg Patriot of September 1, 1886. |
| 11 | Hazelwood | Allegheny | 40 24 | 79 59 | 3 | | | | R. Balling | Second floor; just retired; each shock accompanied by rumbling; second most severe; undulatory and vibratory motion following quick movement of spring mattress; "NW. by W. to SE. by E.;" basin, pitcher, etc., not disturbed. |
| 12 | Howard | Centre | 41 01 | 77 44 | | | | | Centre Reporter | Shocks were felt; some got out of bed to find cause of disturbance. |
| 13 | Hulton | Allegheny | 40 33 | 79 52 | 2 | | | | W. Wade | In bed, second story, frame house, strongly built; windows rattled; people awakened; second shock less severe, but rattled windows. |
| 14 | Laporte | Sullivan | 41 26 | 76 34 | | | | | W. Spencer, postmaster. | Not felt. |
| 15 | Macungie | Lehigh | 40 31 | 75 32 | | SE. to NW | | | C. H. Pems | Information from reliable observers, second floor stone house, a door swung open (set in SW. to NE. wall); house on ground overlying strata of limestone. |
| 16 | Meadville | Crawford | 41 39 | 80 11 | 2 | | | 20 | Associated Press, September 1, 1886. | Shocks successive; second, slight; streets filled with people; guests rushed from hotels in night clothes; women and children cried and screamed; no damage known. |
| | do | do | 41 39 | 80 11 | 2 | | | 20 | Columbus (Ga.) Sun | "Very light;" entire duration, twenty seconds. |
| | do | do | 41 39 | 80 11 | | | | | New York World and New York Sun. | |
| 17 | Media | Delaware | 39 55 | 75 24 | | | | 3 to 5 | W. H. Tricker | Severe shock; duration, three to five seconds; followed in a few seconds by a second; windows rattled so that I went out to see if any one was at the door. |
| | do | do | 39 55 | 75 24 | | | | 5 | J. L. Rigby | Three miles west of Media; was on porch; felt tremor and saw gate swing. |
| | do | do | 39 55 | 75 24 | | N. to S | | | L. S. Hough | Observations by various parties in and about town; rumbling; generally felt in all parts of house; wood-work creaked; doors and windows rattled; beds shook; undulatory. |
| 17 | Media | Delaware | 39 55 | 75 24 | 1 | | | 10 | L. S. Hough | Continuous tremor. Felt by few; rattling windows. Soil of disintegrated gneiss, the underlying rock. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**PENNSYLVANIA—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | m. | s. | | |
| 18 | Montrose | Susquehanna | 41 50 | 75 56 | | | | | J. R. Raynsford, postmaster. | Not felt. |
| 19 | Mt. Holly Springs | Cumberland | 40 06 | 77 13 | | | | | H. M. Johnson | At foot Blue Mountains; house shook; rocked like a ship; could hardly stand. |
| 20 | Myerstown | Lebanon | 40 22 | 76 20 | | | | | S. C. Stambaugh | Second floor, brick house; people awakened, and some felt dizzy. |
| 21 | New Castle | Lawrence | 41 01 | 80 24 | 2 | | | 40 | J. M. Butz | Sitting in chair on second floor; house on hill; a slight trembling, increasing till books in library moved to and fro; mirror, lamp, etc., moved violently; shock gradually diminished. Interval, eight minutes; second, slight. No damage on high elevations, but on the flat several houses so warped the doors could not be opened. A news paper "slip" says: "No noise; buildings shook, clocks stopped, pictures, chandeliers and hanging ornaments swayed N. to S., sleepers awakened." One block shook so violently all left rooms: many undressed. Manager opera-house, sleeping in upper story, Leslie House, ran to the street half-dressed; says building rocked 6 inches, Guests left hotels and in one electric bells all rang. Children cried. Three distinct shocks. |
| 22 | Germantown | Philadelphia | 40 02 | 75 12 | 1 | | | 10 | J. W. Redway | Very light; not felt by those walking; felt by a few sitting or lying down on first floors; felt perceptibly by most people on second and third floors. Best reports make duration ten seconds. A few claim they heard noise; probably passing of trains. |
| 23 | Philadelphia | ...do | 39 57 | 75 09 | 2 | | | | Associated Press | Two very distinct shocks; interval, eighteen minutes; high buildings rocked and windows rattled; many rushed from beds; no damage. |
| | ...do | ...do | 39 57 | 75 09 | | W. to E. | | 30 | Chicago Inter Ocean and Florida Times-Union, September 1, 1886. | "Felt here." |
| | ...do | ...do | | | | E. to W. | 1 | | Signal Service observer | "Very perceptible." Vibrations, two a second; interval, thirteen minutes; second, slight; no damage. |
| | ...do | ...do | 39 57 | 75 09 | | | | | L. M. Haupt, A. M., civil engineer. | Not felt; was sitting on porch large stone mansion full of people. Had there been shock it would have certainly been noticed. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**PENNSYLVANIA—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | *m.* | *s.* | | |
| | Philadelphia | Philadelphia | 39 57 | 75 09 | 1 | | | | "The Times" | No noise; felt by every one in upper stories: chandeliers swayed, chairs moved, etc.; duration, a few seconds. |
| | do | do | 39 57 | 75 09 | 3 | | | | Miss Emma Walters | Shocks of decreasing intensity; intervals, a few minutes each. In second story, brick building; chandelier suspended from center of ceiling, 3 feet long, weight about 25 pounds, appeared to swing SE. to NW., and during first shock to have a twisting motion in addition: no movements of floor nor rattle of windows. (Professor Heilprin recommends Miss Walters as an absolutely reliable observer, being, etc). |
| | do | do | 39 57 | 75 09 | | N. to S | | | Miss J. L. Carr | "Very light;" noticed slightly in third story; bed moved slightly, etc. Decidedly undulatory, causing slight dizziness. |
| | do | do | 39 57 | 75 09 | | | | | E. D. Cope | "Did not feel it." |
| 24 | Pittsburgh | Alleghany | 40 28 | 80 01 | | | | 30 | Associated Press | Felt in all parts of city; greatest consternation in large buildings and hotels; guests rushed to the streets; swaying quite perceptible in upper stories Western Union Telegraph building. Party sitting in fifth story Hotel Duquesne; building rocked; felt nausea; saw City Hall, immense stone structure, just opposite, tremble and sway. Severest on South Side; dishes thrown from shelves, clocks stopped, and people rushed out of houses screaming. Members Lotos Club greatly frightened; adjourned and left building hastily. Surrounding towns report distinct vibration. |
| | do | do | 40 28 | 80 01 | 2 | | | | Chicago Herald, Louisville Commercial, and Knoxville Journal, September 1, 1886 | First, slight; interval, twelve minutes; second, severe; large buildings violently shaken; hotel guests panic-stricken; no damage. |
| | do | do | 40 28 | 80 01 | | | | | New York Tribune, September 1, 1886. | Flow of natural gas diminished in Washington and Westmoreland counties. The pressure of Grapeville well, 20 miles from here, increased from 800 to 1,000 pounds to the square inch, and the flow is uncontrollable. Pennsylvania Company is unable to supply one mill. The Philadelphia is unable to supply three of its manufacturing customers. Decrease in flow attributed by some to earthquake; officials investigating cause. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**PENNSYLVANIA—Continued.**

| No. | Locality. | County. | Latitude. ° ′ | Longitude. ° ′ | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | Pittsburgh | Allegheny | 40 28 | 80 01 | | | | | New York Sun | |
| | do | do | 40 28 | 80 01 | 1 | | | 30 | Columbus (Ga.) Sun | |
| | do | do | 40 28 | 80 01 | 2 | | | 30 | Pittsburgh Dispatch, September 1, 1886. | "Two distinct, sharply-defined shocks;" damage very slight; most marked in upper stories of lofty buildings in lower part of city; according to many it followed the rivers, or was severest near them. Not felt by those walking. Fire-alarm operators on top City Hall felt four distinct shocks at intervals of ten, twenty, and twenty-five minutes; first shock, severe and sudden; direction E. to W. by motion of liquids in jars. At Western Union building the operator was receiving dispatch from Indianapolis; when last letter of "earthquake" was spelled out table began to rock back and forth; other tables followed; much alarm; lasted twenty seconds; clock stopped. Felt distinctly at City Poor Farm, up the Monongahela; inmates all asleep and therefore no excitement; watchmen felt distinct tremor. Severe shock at Homeopathic hospital; all inmates felt tremor; so short, no excitement. Not felt at West Penn hospital. Warden in main part of penitentiary felt nothing, but two distinct tremors were felt by family at residence, facing the river; thinks it followed river. Not felt by Claremont officials. Careful observer, with watch in hand, says duration ten or twelve seconds. |
| | do | do | 40 28 | 80 01 | 1 | | | 30 | L. E. Stofiel, editor Commercial Gazette | No noise, tremor, or jar; duration nearly half minute. |
| | do | do | 40 28 | 80 01 | | | | | Rev. D. C. Byllesby | Very perceptibly felt. |
| | do | do | 40 28 | 80 01 | | | | | C. Paine | Walking out doors, 3 miles east of Union Depot; did not notice shock; slight vibrations noticed in upper stories. |
| | do | do | 40 28 | 80 01 | | | | | G. Westinghouse | Was in office; not noticed; in upper stories chandeliers swung considerably; no noise or jar. |
| | do | do | 40 28 | 80 01 | | | | | J. D. Weeks, editor | Clock stopped; pictures thrown from wall of "Duquesne Club;" water in well tasted of petroleum; when cleaned out petroleum found oozing through walls. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**PENNSYLVANIA—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | m. | s. | | |
| | Pittsburgh | Allegheny | 40 28 | 80 01 | | | | | Pittsburgh Dispatch, September 2, 1886. | Professor Vevay, Allegheny Observatory, reports that neither his delicate clocks nor other scientific instruments were disturbed. |
| | do | do | 40 28 | 80 01 | 1 | | | | Signal Service observer | Slight shock; duration from one-half to one and a half minutes; no damage reported. Professor Vevay, of Allegheny Observatory, says: Not felt at Observatory. |
| | do | do | 40 28 | 80 01 | | | | 20 | Signal Service observer | No noise. |
| 25 | Pottsville | Schuyler | 40 42 | 76 73 | | | | | P. W. Sheafer, engineer and geologist | Old lady felt slight tremor; no one else felt it (supplement to former negative report). |
| 26 | Presqueville Light-station. | | 42 09 | 80 07 | | | | | Louis Vannatta, keeper | Not felt. |
| 27 | Primos | Delaware | | | | | | | Mrs. A. H. Kimple | Violent trembling of bed and rattling of windows; alarm for safety of house; servants in third story badly frightened. |
| 28 | Reading | Berks | 40 20 | 75 55 | 2 | | | | Harrisburg Daily Patriot, September 2, 1886. | Felt very perceptibly in city and vicinity; people awakened and many on streets at midnight discussing it; clocks stopped, windows rattled, and doors were slammed. Interval, twelve or fifteen minutes. |
| 29 | Scranton | Lackawanna | 41 24 | 75 43 | 2 | | | | Associated Press | "Two very distinct shocks." Interval, twelve minutes. In a fifth story, suspended objects swung, and considerable consternation prevailed. Felt in various parts of city, especially in high buildings. |
| | do | do | 41 24 | 75 43 | | | | | New York Herald | |
| 30 | Selin's Grove | Snyder | 40 48 | 76 55 | | | | 30 | J. G. L. Shindell | Rattling of windows; no damage. |
| 31 | Sewickley | Allegheny | 40 33 | 80 13 | 3 | | | | S. H. Murray | First shock heaviest; bowl, 5 inches in diameter, filled nearly full, had waves ¼-inch high; second, one-third as severe; shook furniture and chandeliers, and alarmed servants in attic; third, one half as heavy as first; second interval five and a half minutes. |
| 32 | Shoemakertown | Montgomery | | | | | | | W. M. Davis | Not felt; sitting in rocking-chair, first floor large house; no one in house felt shock. Not noticed by more than 5 per cent. of population. |
| 33 | Titusville | Crawford | 41 38 | 79 45 | | | | | New York Times, Sept. 1, 1886. | "Was felt;" guests in hotel and compositors on third floor frightened; no damage; not felt except in high buildings. |
| | do | do | 41 38 | 79 45 | | | | | New York Sun | |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**PENNSYLVANIA—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | m. | s. | | |
| 34 | Uniontown | Fayette | 39 55 | 79 44 | 1 | E. to W. | | 8 or 10 | F. C. Robinson, M. D. | Town on stiffy clay, over limestone shales, etc.; bituminous coal measure 300 feet below; two and a half miles W. of Laurel Hill, the most western ridge of the Alleghenies; elevation of town 1,000 feet; sudden and heavy jar as of some one falling in adjoining room; then violent vibrations of bed; not half the people felt the shock; generally noticed by those in bed in upper stories; one gentleman felt second shock fifteen minutes later; felt very slightly in the mountains, if at all. |
| 35 | Unionville | Chester | 39 54 | 75 45 | 2 | | | | No name | Windows rattled, beds shook violently, dog frightened. |
| 36 | Wernersville | Berks | 40 20 | 76 05 | | | | | Harrisburg Daily Patriot, Sept. 2, 1886. | Guests at hotel awakened, and some thought building was about to tumble. |
| 37 | Williamsport | Lycoming | 41 15 | 77 04 | 3 | | | | do | Shock very sensibly felt at different points in city; duration a few seconds; second shock less violent and a few seconds later; third shock felt very distinctly; not felt at Milton and other places near Williamsport. |
| 38 | Youngsville | Warren | 41 51 | 79 23 | | S. to N. | | | Mrs. V. L. Thomas | (Information through others.) Noise accompanied by tremor; direction N. to S. One party felt two shocks, duration one second each; interval two seconds, direction NE. to SW. Another, one shock, lasting two or three seconds, observer two miles east; three distinct shocks, duration four or five seconds each; total duration ten minutes. Stoves and dishes rattled and light objects thrown down; pan thrown from shelf; sleepers awakened and much alarmed. |

**RHODE ISLAND.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Block Island, N. light. | Newport | 41 14 | 71 34 | | | | | H. D. Ball, keeper | Not felt. |
| 2 | Block Island, S. E. light. | do | 41 09 | 71 33 | | | | | H. W. Clark, keeper | Do. |
| 3 | Block Island | do | | | | | | | W. M. D. | Do. |
| 4 | Bristol | Bristol | 41 41 | 71 17 | | | | | do | Do. |
| 5 | Kingston | Washington | 41 29 | 71 31 | | | | | J. Bartlett | Do. |
| 6 | Providence | Providence | 41 49 | 71 23 | | | | | W. M. D. | Felt. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**SOUTH CAROLINA.**

| No. | Locality. | County. | Latitude, | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | *m.* | *s.* | | |
| 1 | Abbeville | Abbeville | 31 11 | 81 25 | | | | | Western Union Telegraph. | Several violent shocks, the first most severe, overthrowing chimneys, moving furniture, shaking houses; general alarm felt; people ran out of houses. |
| 2 | Acton | Richland | 33 55 | 80 40 | | NW. to SE | | | J. D. Prout | Vertical. Very severe shocks, especially the first; pictures thrown from walls, chimneys broken. |
| 3 | Adams Run | Colleton | 32 46 | 80 20 | | | | | Associated Press | |
| 4 | Aiken | Aiken | 33 34 | 81 10 | | E. to W | | | Charleston Year Book. | Rang church bells. |
| | ....do | ....do | 33 34 | 81 10 | | | | | | Frame house, two stories, on brick piers: house rocked, window-weights rattled, pictures thrown down, plastering cracked. |
| 5 | Allendale | Barnwell | 3 02 | 81 12 | | | | | Charleston Year Book. | Chimneys broken and overthrown, articles on tables and mantels thrown down, church bells rang by first shock, fowls shaken from their roosts. |
| 6 | Allen's Bridge | | | | | N. to S | | | R. Campbell | Several severe shocks the first most severe; houses badly shaken, loud, rumbling sounds, people remained out of doors all night. |
| 7 | Alston | Fairfield | 34 15 | 81 18 | | SE. to NW | | | A. P. Danks | Houses rocked like a boat at sea, chimneys overthrown, fowls shaken from roosts, water thrown from vessels. |
| 8 | Anderson | Anderson | 34 30 | 82 39 | 6 | | | | Charleston Year Book. | First very severe; third and sixth also severe; bell in court-house rang by first shock; clocks stopped, lamps put out, and glasses thrown from sideboards. |
| 9 | Antreville | Abbeville | 34 20 | 81 34 | | | | | C. H. Torry | Eight or ten shocks; violent swaying of house; objects thrown from mantels; rumbling heard; consternation among men and animals. |
| 10 | Appleton | Barnwell | 33 03 | 81 18 | | | | | W. E. Hayes | Furniture moved about, objects overturned, great terror among negroes, several chimneys broken. |
| 11 | Arnold's Mills | Pickens | 34 49 | 82 32 | | | | | E. M. Caperton | Several shocks felt, but no damage done beyond cracked plastering. |
| 12 | Arrowwood | Spartanburgh. | 35 04 | 81 45 | | | | | A. Pursell | Houses shaken; people alarmed; plastering cracked. |
| 13 | Baldock | Barnwell | 33 05 | 81 20 | | | | | J. Cashiel | Very violent shock; chimneys broken; a sink in the ground took place 3 miles to the eastward. |
| 14 | Bamberg | ....do | 33 12 | 81 13 | | | | | Charleston Year Book. | Several brick houses badly damaged by cracking of walls and falling of plaster; people camped in the open air. |
| 15 | Barmoris | Abbeville | 34 21 | 82 28 | | | | | Western Union Telegraph. | Similar effects to those at Abbeville. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**SOUTH CAROLINA—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | m. | s. | | |
| 16 | Barnwell | Barnwell | 33 12 | 81 13 | | | | | W. E. Collier | Severe shock, alarming everybody; houses rocked and shook as if about to fall; light objects thrown about, furniture moved, walls cracked, and plastering shaken down. |
| 17 | Batesburgh | Lexington | 34 53 | 82 15 | | | | | C. W. Aldrich | Several sharp shocks; first most violent; ten shocks between 10 p. m. and 9 a. m.; plastering and chimneys shaken down; general alarm among whites, and especially blacks. |
| 18 | Bath | Aiken | 33 31 | 81 45 | | | | | D. Middleton | Extremely violent shock, producing general consternation and alarm; houses swayed, walls cracked, chimneys broken, clocks stopped. |
| 19 | Beaufort | Beaufort | 32 23 | 80 42 | 15 to 17 | | | | Associated Press | Chimney tops shaken down; clocks stopped; pictures and mirrors shaken; people greatly alarmed, especially the blacks, by the first shock; people remained in the streets and fields all night; negro church bells were tolled, and thousands congregated and remained in prayer all night. |
| | do | do | 32 23 | 80 42 | | | | | Charleston Year Book | Very severe shock, lasting thirty seconds; two others of less severity felt within ten minutes, five minutes apart; at intervals, varying in duration until 10.45, twelve distinct convulsions felt; other shocks occurred during the night; some of the large buildings cracked; at Island Tank a space about 60 feet in circumference sunk about 2 feet below surrounding level, leaving fissures in the ground. |
| 20 | Beaver Pond | Lexington | 33 47 | 81 10 | | | | | C. W. Aldrich | Houses considerably shaken. |
| 21 | Beech Island | Aiken | 33 23 | 81 48 | | | | | A. Clarkson | Alarm among men and animals. |
| 22 | Belton | Anderson | 34 30 | 82 30 | | | | | C. A. Vance | Decidedly strong shock, followed by several lighter ones; no serious damage beyond cracked plastering. |
| 23 | Bennettsville | Marlborough | 34 40 | 79 40 | | | | | Charleston Year Book. | Severe shocks felt all over the county between 10 and 11 o'clock, with two more after midnight; great excitement among all classes and a panic among negroes; no serious damage reported; several chimneys toppled over. |
| 24 | Bishopville | Sumter | 34 14 | 80 16 | | | | | Charles Mann | Very severe, but only minor damages. |
| 25 | Black Mingo | Williamsburgh | 33 26 | 79 35 | | | | | W. Rud | Great alarm throughout the neighborhood; negroes panic-stricken; houses much shaken; chimneys overthrown; plastering shaken down; some walls cracked. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**SOUTH CAROLINA—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. |  | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  | ° ″ | ° ′ |  |  | *m.* | *s.* |  |  |
| 26 | Black's Station | York | 35 05 | 81 30 |  |  |  |  | W. Williston | Very severe shocks; people driven out of houses for fear of being killed; general terror throughout the neighborhood. |
| 27 | Blairsville | do | 34 55 | 81 22 | 3 |  |  |  | G. B. Tolliver | Violent shocks between 10 and 10.30; people very much alarmed. |
| 28 | Bloody Point Station |  |  |  | 9 |  |  |  | J. M. Doyle, keeper |  |
| 29 | Bluffton | Beaufort | 32 15 | 80 05 | 5 |  |  | 3 to 5 | Charleston Year Book. | A rumbling was heard, and almost simultaneously houses commenced shaking and cracking as though about to fall. The observer was in the yard, and could see the trees shaking and see and feel the ground vibrating, accompanied by heavy rumbling, which passed away to the eastward; four shocks followed, each less violent than the preceding one and at longer intervals. |
| 30 | Blythewood | Fairfield | 34 16 | 80 58 |  |  |  |  | J. Bonneau | Walls cracked; plastering dislodged; panic among negroes. |
| 31 | Bonneau's | Charleston | 33 18 | 79 55 |  |  |  |  | Charleston Year Book. | Several shocks; the earth sank in places; one of the sinks about 30 feet in diameter and the greatest depth 12 feet. |
| 32 | Branchville | Orangeburgh | 33 30 | 80 50 |  |  |  |  | E. Sloan |  |
| 33 | Brewerton | Laurens | 34 26 | 82 15 | 7 or 8 |  |  |  | W. E. Coster | Very violent shocks, the first of a most alarming character. |
| 34 | Brighton | Hampton | 32 40 | 81 15 |  |  |  |  | M. Conner | Houses moved from foundations; chimneys destroyed; ground sank in several places. |
| 35 | Brightsville | Marlborough | 33 45 | 79 36 | 6 or 7 |  |  |  | F. B. Cress | Accompanied with noise like railroad train; first shock violent enough to topple chimneys, knock furniture about, and break windows. |
| 36 | Brown's Ferry | Georgetown | 33 33 | 79 23 | 10 |  |  |  | H. Meyer | First shock was terrible, seeming as if no structure could withstand it; people did not dare to go to bed; loud rumbling; the jar was like riding in a wagon without springs. |
| 37 | Brunson | Hampton | 32 57 | 81 08 |  |  |  |  | J. Kershaw | General panic among negroes; whites much alarmed; furniture thrown violently about; chairs overturned. |
| 38 | Bucksville | Horry | 33 48 | 79 02 |  |  |  |  | Charleston Year Book. | First shock lasted at least forty-five seconds; five shocks followed before midnight, the first and fourth being the most severe; others were felt later in the night; all were preceded by a rumbling resembling that made by a passing train of cars; the whites were awe-stricken and all turned out and gathered in groups on the streets. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**SOUTH CAROLINA—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | m. | s. | | |
| 39 | Buena Vista | Greenville | 34 57 | 82 15 | | | | | R. W. Temple | Several shocks, the first causing general alarm; bricks thrown from chimneys; plastering cracked. |
| 40 | Buford's Bridge | Barnwell | 33 08 | 81 10 | | | | | N. Gassoway | The whole neighborhood violently shaken; several sink-holes reported as formed; great terror among negroes. |
| 41 | Bull Creek | Horry | 33 41 | 79 02 | 8 or 10 | | | | F. G. Schernber | First most alarming; chimneys broken and people driven from houses; the surrounding country much shaken, and general feeling of fear and apprehension. |
| 42 | Bull's Bay | | | | | | | | Light-House Board | |
| 43 | Calhoun's Mills | Abbeville | 33 55 | 82 20 | | | | | R. W. Marshall | Several severe shocks; considerable alarm, but no serious damage. |
| 44 | Camden | Kershaw | 34 16 | 80 38 | | | | | Charleston Year Book. | The shock produced a fissure in the earth about 12 miles from town. |
| 45 | Campbell's Bridge | Marion | 34 18 | 79 14 | | | | | J. Ranney | Terrible shock, followed in a few moments by several lighter ones; houses greatly shaken, chimneys overthrown. |
| 46 | Campton | Spartanburgh | 35 03 | 82 04 | | | | | G. M. Aultman | Effects as violent as at Spartanburgh. |
| 47 | Cape Roman Light-tower. | Charleston | 33 02 | 79 20 | | | | | Light-House Board | Severe shocks; cracks in house and chimneys. |
| 48 | Cartersville | Darlington | 34 04 | 80 00 | | | | | A. M. Rosenberg | Very violent shock, causing people to leave houses in terror; buildings rocked and swayed like a boat at sea; some large fissures formed. |
| 49 | Cashua Ferry | Marlborough | 34 23 | 79 42 | | | | | F. Legan | The country round about much shaken and people greatly alarmed. |
| 50 | Cedar Bluff | Union | 34 44 | 81 46 | | | | | G. E. Morgan | Several chimneys broken; objects thrown from mantels and shelves; great deal of apprehension and excitement. |
| 51 | Cedar Shoal | Chester | 34 40 | 80 55 | | | | | C. Sevier | Most violent shocks ever felt here; buildings badly shaken. |
| 52 | Cedar Spring | Spartanburgh | 34 05 | 81 19 | | | | | G. M. Aultman | Effects as violent as those at Spartanburgh. |
| 53 | Central | Pickens | 34 46 | 82 42 | | | | | F. W. Bishop | Houses considerably shaken, but no damage done; accompanied by rumbling. |
| 54 | Chappell's (Bridge) | Newberry | 34 16 | 81 18 | | | | | M. B. Clark | Most violent ever known; people almost panic-stricken; chimneys broken and houses disturbed on their foundations. |
| 55 | Charleston | Charleston | | | | | | | | |
| 56 | Charleston Main Light-tower. | | | | | | | | Light-House Board | Vibrated violently and cracked in places; sand-holes and fissures in ground. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**SOUTH CAROLINA—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | *m.* | *s.* | | |
| 57 | Cheraw | Chesterfield | 34 41 | 79 55 | | | | | Charleston Year Book. | First shock lasted fully two minutes, and was preceded and followed by a rumbling which could be heard for some time as it died away; people stood up with difficulty; buildings rocked like the branches of a tree; windows were broken, furniture upset, chimneys demolished, and other slight damages done; a half dozen light shocks followed before 2 a. m.; many remained out of doors all night. |
| | ......do | ....do | 34 41 | 79 55 | | | | | W. R. Godfry | Several shocks; first most severe, lasting two minutes; fourth next in severity, lasting fifty seconds; intervals 7, 5, 5 minutes respectively. First shock rocked houses violently, cracking and creaking timbers; several chimneys thrown down; accompanied by loud rumbling. |
| 58 | Chester | Chester | 34 40 | 81 13 | | | | | Charleston Year Book. | Farmers tell of shaking houses and of the fright of animals as well as of terrified humanity. |
| 59 | Chesterfield | Chesterfield | 34 44 | 80 05 | | | | | ......do | Brick walls badly cracked. |
| 60 | Claremont | Sumter | 33 59 | 80 33 | | | | | R. E. Holston | First very violent; ground undulated so it was difficult to stand; houses more or less damaged. |
| 61 | Clark's Hill | Edgefield | 33 44 | 82 07 | | | | | United Press | Houses swayed and cracked; people almost in a panic. |
| 62 | Clinton | Laurens | 34 29 | 81 52 | 8 or 10 | | | | R. E. Newmann | Loud roaring; rolling of the ground; shaking of houses; people terrified. |
| 63 | Clio | Marlborough | 34 37 | 79 35 | | | | | A. A. Schmidt | The greatest alarm and consternation; plastering broken; chimneys thrown down; loud sounds like subterranean thunder. |
| 64 | Columbia | Richland | | | | | | | R. W. Shand, attorney | |
| 65 | Cokesbury | Abbeville | | | | | | | United Press | Buildings violently shaken, bringing people to the street in terror and confusion. |
| 66 | Conway | Horry | 33 53 | 79 00 | | | | | Morning Star, September 4, 1886. | Duration about a minute: many clocks stopped, crockery rattled, vases thrown from bureaus, and books from tables. |
| | ......do | ....do | 33 53 | 79 00 | | | | | Charleston Year Book. | The first two shocks were quite severe, the most substantial building seemed in great danger of being shaken to pieces; many sought refuge on a steamer and she was soon loaded to the utmost capacity, but the shocks were as plainly felt on board; many shocks were felt between 10 and 11 o'clock and several about 1 o'clock. |
| 67 | Cool Spring | ....do | 34 00 | 79 08 | | | | | Morning Star | Similar effects to those at Conway. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**SOUTH CAROLINA—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks, | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | m. | s. | | |
| 68 | Coosaw | Beaufort | 34 29 | 80 43 | | | | | U. Legan | Ground raised and depressed, with cracks; houses moved from foundations; furniture overturned. |
| 69 | Cottonville | | | | | | | | Charleston Year Book. | Every chimney damaged; people panic-stricken. |
| 70 | Cowpens | Spartanburgh | 35 01 | 81 45 | | | | | G. M. Aultman | Effects apparently as violent as at Spartanburgh. |
| 71 | Darlington | Darlington | 34 16 | 79 50 | | | | | Associated Press | Walls cracked, chimneys overthrown; general terror. |
| 72 | Dawfuskie Island Light-house. | | | | | | | | P. Comer, keeper | |
| 73 | Donnaldsville | Abbeville | 34 20 | 82 28 | | | | | Western Union Telegraph. | Similar to effects at Abbeville. |
| 74 | Dove's Station | Darlington | 34 23 | 79 55 | | | | | Associated Press | Similar to effects at Darlington. |
| 75 | Due West | Abbeville | 34 16 | 82 22 | | | | | Western Union Telegraph. | Similar to effects at Abbeville. |
| 76 | Duncans | Spartanburgh | | | | | | | G. M. Aultman | Effects similar to those generally felt throughout the county. |
| 77 | Early Branch | Hampton | 32 44 | 80 55 | | | | | Charleston Year Book. | First shock was quite violent, causing houses to tremble and move on their foundations; the people ran into the streets; two or three slight shocks followed; no damage done. |
| 78 | Easley | Pickens | 34 39 | 82 31 | | | | | F. W. Bishop | Very forcible. |
| 79 | Eastover | Richland | 33 56 | 80 44 | | | | | E. M. Collins | About as violent as in Columbia. |
| 80 | Edgefield | Edgefield | 33 49 | 81 55 | | | | | Associated Press | Houses shaken violently, walls cracked, and chimneys thrown down. |
| 81 | Edisto Island | | | | | | | | Charleston Year Book. | Many chimneys thrown down; people panic-stricken. |
| 82 | Effingham Station | Marion | 34 04 | 79 45 | | | | | Associated Press | People terror-stricken; rents made in the ground and houses seemed about to fall. |
| 83 | Elko | Barnwell | 33 23 | 81 19 | | | | | S. B. Ridgway | Extremely violent and terrifying; similar to Blackville. |
| 84 | Ellenton | ...do | 33 18 | 81 37 | | | | | Charleston Year Book. | The first and severest shook houses at a terrible rate; six shocks felt in a little over an hour; others of less force perceptible to 8 o'clock a. m.; a roaring as of heavy thunder could be heard for some time before and after each disturbance; persons differ as to the direction; not much damage. |
| 85 | Equality | Anderson | 34 44 | 82 37 | | | | | E. A. Vance | Reported to have been very violent and alarming. |
| 86 | Entawville | Berkeley | 33 25 | 80 20 | 11 | | | | Charleston Year Book. | No damage, except to plastering. |
| 87 | Florence | Darlington | 34 10 | 79 45 | | | | | Associated Press | Similar to effects at Darlington. |
| 89 | Foreston | Clarendon | 33 40 | 80 00 | | | | | E. N. Pope | |
| 90 | Forestville | Marion | | | | | | | United Press | Extremely forcible; several shocks reported in vicinity. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**SOUTH CAROLINA—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | *m.* | *s.* | | |
| 91 | Fort Ripley Shoal Light-house. | | | | | | | | Light-House Board | Particularly heavy shocks, from south and west; pictures on north walls were reversed; the structure settled considerably, with excess of 3 inches on southeast corner. |
| 92 | Fraziersville | Abbeville | 34 04 | 81 19 | | | | | Western Union Telegraph. | Reported very violent, causing much consternation. |
| 93 | Frogmore | Beaufort | 32 16 | 80 35 | | W. to N. | | | W. Hoxie | |
| 94 | Gadsden | Richland | 33 52 | 80 45 | 8 or 10 | | | | E. M. Collins | Houses violently shaken, walls cracked, chimneys overthrown. Equally violent throughout surrounding parts. |
| 95 | Gaffney | Spartanburgh. | 35 04 | 81 36 | | | | | Charleston Year Book. | The first shock was violent and startling, and was followed by five others at intervals; strange subterranean detonations or rattlings preceded the first shock. |
| 96 | Georgetown | Georgetown | 33 22 | 79 17 | | | | | A. Macbeth | |
| | do | do | 33 22 | 79 17 | | E. to W. | | | M. S. Iseman, M. D. | A few chimneys thrown down and brick parapets dislodged. Brick buildings undulated and people fled from houses. |
| 97 | Georgetown Light-House. | | | | | | | | Light-house Board | Shock severe; fences thrown from pedestal to north and east; lamp capsized; chimneys of house cracked. |
| 98 | Gilbert Hollow | Lexington | 33 56 | 81 23 | | | | | C. W. Aldrich | Similar to Batesburgh. |
| 99 | Gillisonville | Hampton | | | | | | | G. F. Smith | Houses moved, ground elevated and depressed in places, fissures formed, from which water flowed; chimneys thrown down; people in a state of terror. |
| 100 | Glymphville | Newberry | | | | | | | J. J. Cummings | Houses shaken violently and people fled from them; plastering shaken down and chimneys broken; eight or ten shocks during the night. |
| 101 | Golden Grove | Greenville | 34 50 | 82 23 | | | | | C. R. Casilear | Violent shock, bringing every one out of the houses; ground undulated in an alarming way; loud rumbling; duration, three minutes, followed by others during the night; eight or ten in all. |
| 102 | Gourdin's Station | Williamsburgh. | 33 29 | 79 53 | | | | | Western Union Telegraph. | Said to have been very violent; depressions formed in the neighborhood. |
| 103 | Graham's | do | 33 50 | 79 45 | | | | | do | Said to be very violent. |
| 104 | Graham's Turn Out | Barnwell | 33 19 | 81 05 | | | | | S. B. Ridgeway | Similar to Blackville. |
| 105 | Grahamville | Beaufort | 32 30 | 81 00 | | | | | Associated Press | |
| 106 | Graniteville | Aiken | 33 35 | 81 44 | | | | | do | Cracked walls, threw down chimneys, extinguished lamps, moved furniture, and threw loose objects about. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**SOUTH CAROLINA—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | m. | s. | | |
| 107 | Granny's Quarter | Kershaw | 34 23 | 80 40 | | | | | United Press | Very forcible and alarming; chimneys overthrown and people afraid to enter their houses. |
| 108 | Greenville | Greenville | 34 50 | 82 23 | | | | | Charleston Year Book. | First shock lasted thirty seconds; a lighter one was felt a few minutes later; people ran out of houses and many feared to return; large stacks of bricks where buildings were being erected were shaken down; no serions damage resulted. |
| 109 | Greenwood | Abbeville | 34 11 | 82 05 | | | | | do | People wild with excitement and in the streets for safety; roaring accompanying the shocks. |
| 110 | Greer's Depot | Greenville | 34 56 | 82 15 | | | | | R. W. Temple | Very badly shaken; general fright; water thrown from tanks. |
| 111 | Guthriesville | York | 34 52 | 81 15 | | | | | M. S. Young | People very much frightened; houses cracked and plastering shaken down. |
| 112 | Hamburgh | Aiken | 33 30 | 81 46 | | | | | D. Middleton | Similar to Langley and Bath in violence. |
| 113 | Hampton | Hampton | | | 7 | | | | Charleston Year Book. | Seven distinct shocks between 10 p.m. and 4 a.m. The first very severe, but causing no serious damage. |
| 114 | Hardeesville | Marion | 34 22 | 79 25 | | | | | G. B. Fullerton | The greatest fear throughout the surrounding country. Only minor damages reported. |
| 115 | Hardeeville | Beaufort | 32 16 | 81 04 | | | | | Savannah Morning News. | |
| 116 | Harpers | Georgetown | | | | | | | T. Huger | Several sinks reported; people in a state of consternation; almost impossible to stand during first shock. |
| 117 | Hodges | Abbeville | 34 16 | 82 15 | | | | | Western Union Telegraph. | Similar to Abbeville. |
| 118 | Honea Path | Anderson | 34 26 | 82 24 | | | | | E. A. Vance | Similar to Belton. |
| 119 | Hopkins Turn Ont | Richland | 33 55 | 80 53 | | | | | E. M. Collins | Houses greatly shaken. |
| 120 | Hornsboro | Chesterfield | 34 42 | 80 05 | 6 or 7 | | | | A. M. Dodge | Most violent and alarming; universal terror; chimneys broken. |
| 121 | Hunting Island Light-station. | Beaufort | 32 23 | 80 25 | 4 | | | | M. B. Trevett, keeper | Clock stopped. |
| 122 | Huntersville | Greenville | 34 46 | 82 10 | | | | | R. W. Temple | Said to have been very violent. |
| 123 | Indiantown | Williamsburgh. | 33 46 | 79 33 | 10 | | | | R. A. Bodine | First shock most violent; houses shaken throughout surrounding country with great violence; chimneys snapped off; people spent the night out doors. |
| 124 | Irvington | Chesterfield | 34 42 | 80 05 | | | | | A. M. Dodge | Similar to Hornsboro. |
| 125 | Jackson Station | Aiken | 33 19 | 81 44 | | | | | United Press | Extremely violent and alarming. |
| 126 | Johnston | Edgefield | 33 49 | 81 45 | | | | 105 | Charleston Year Book. | About ten shocks occurred during the night and early morning; things rattled considerably; people ran out of houses. |

*Report of earthquake observations, earthquake of August 31, 1886*—Continued.

**SOUTH CAROLINA—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | m. | s. | | |
| 127 | Kingsburg | Lancaster | 34 31 | 80 55 | | | | | J. Ballard | Said to have been very violent. |
| 128 | Kingstree | Williamsburgh. | 33 41 | 79 44 | | | | | Associated Press | Felt with great force. |
| 129 | Kingsville | Richland | 33 49 | 80 41 | | | | | Western Union Telegraph. | For a few minutes it seemed as if everything must fall. |
| 130 | Kirkwood | Kershaw | 34 20 | 80 36 | | | | | | Same as at Camden. |
| 131 | Lancaster | Lancaster | 34 42 | 80 47 | | S. to N. | | | J. H. Foster | Loud roaring, with terrible shaking and settling of house; cows lowed; dogs howled. |
| 132 | Langley | Aiken | 33 33 | 81 45 | | | | | Associated Press | Houses badly shaken and glasses broken; the dams broke loose destroying 1,000 feet of railroad; terrible suffering among the inhabitants. |
| 133 | Laurens | Laurens | 34 30 | 82 02 | | | | | Charleston Year Book. | Shook houses and threw bricks from chimneys; people ran out of their houses and clung to trees for support. |
| 134 | Lee's | Barnwell | 33 19 | 81 10 | | | | | S. B. Ridgeway | Similar to Blackville and Barnberg. |
| 135 | Leesville | Lexington | 33 56 | 81 31 | | | | | Charleston Year Book. | First shock violent and accompanied by much noise; houses rocked and people ran into the streets. Several lesser shocks felt within the house and again between 3 and 5 o'clock a. m. |
| 136 | Lexington | do | 34 57 | 81 13 | | | | | Associated Press | Same as at Leesville. |
| 137 | Liberty | Pickens | | | | | | | F. W. Bishop | Similar to Easley. |
| 138 | Liberty Hill | Kershaw | 34 28 | 80 48 | | | | | J. Ballard | Said to have been very violent. |
| 139 | Little Rock | Marion | | | 8 or 10 | | | | E. M. Hawkins | Eight or ten severe shocks; the country round about in a state of great apprehension; people fled from houses and many feared to return. |
| 140 | Lowndesville | Abbeville | 34 08 | 82 32 | 8 | | | | Atlanta Constitution | Severely felt, alarming people, who ran out of their houses. |
| 141 | Lynchburgh | Sumter | 34 03 | 80 04 | | | | | S. P. Atkinson | First shock broke chimneys, overturned chairs and other objects; several subsequent shocks followed and still others during the night. |
| 142 | McClellanville | Charleston | | | | | | | Charleston Year Book. | The first and hardest shock put everybody and all the animals into such a state of wild excitement that for a while a panic was feared; several houses moved from their places several inches; the shocks continued at irregular intervals during the night and following day, seeming to come from the ocean and run up and down the coast, the roar preceding each. At 6 p. m. (September 1) there came a roaring from the southwest, followed immediately by a trembling and shaking almost as severe as the great shock of Tuesday. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**SOUTH CAROLINA—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | m. | s. | | |
| 142 | McClellanville | Charleston | | | | | | | News and Courier, September 4, 1886. | Terrible shock; general panic; houses moved several inches; roaring from the southwest. |
| 143 | McConnellsville | York | 34 48 | 81 15 | | | | | M. S. Young | Similar to Guthriesville. |
| 144 | Manning | Clarendon | 33 40 | 80 10 | | | | | Western Union Telegraph. | Several severe shocks; the first most violent, shaking houses fearfully and doing some damage; brick walls cracked; people in a state of terror. |
| 145 | Mapleton | Abbeville | 33 41 | 82 18 | 2 | SE. to NW | | | W. Bradley | Interval, three or four minutes; first accompanied by roaring; broke crockery on table and rocked people in bed. |
| 146 | Marion | Marion | 34 11 | 79 20 | | N. to S. | | | Associated Press | Very forcible shock, followed by several others; brick walls cracked and chimneys broken; loud roaring; people much frightened. |
| 147 | Martin's Industry Light-ship. | | | | | | | | J. Masson | |
| 148 | Martin's Industry Shoal Light-ship. | | | | | | | | Light-House Board | Felt shock distinctly; severe jarring sensation; shock came from south and west. |
| 149 | Mars Bluff | Marion | 34 12 | 79 40 | | | | | Western Union Telegraph. | Country roundabout severely shaken and everybody greatly alarmed. |
| 150 | Mayesville | Sumter | 33 58 | 80 11 | | | | | S. P. Atkinson | Very terrifying, but no serious damage; negroes panic-stricken. |
| 151 | Midway | Barnwell | 33 18 | 80 57 | 15 | | | | Charleston Year-Book | One man thought dynamite had been exploded under his house, and seeing a negro running and yelling snapped his gun at him. |
| 152 | Mount Pleasant | Berkeley | | | | E. to W | | | | |
| 153 | Mullins | Marion | 34 12 | 79 13 | | | | | Western Union Telegraph. | Similar to Florence and Marion Court House. |
| 154 | Newberry | Newberry | 34 15 | 81 34 | | | | | Charleston Year Book | Shocks felt all over county, but no damage done. |
| 155 | Nichols | Marion | 34 15 | 79 06 | | | | | Western Union Telegraph. | Similar to Marion Court House. |
| 156 | Ninety-six | Abbeville | 34 10 | 82 01 | | | | | New York Herald, October 12, 1886. | Dispatch from J. McD. Kinard, living 4 miles south of Ninety-six, and others, speaks of underground noises since January, 1885. |
| | ......do | ....do | 34 10 | 82 01 | | | | | New York Times, September 16, 1886. | Strange and unaccountable noises, over an area of 8 or 10 square miles, heard for the last five months; was commented upon in May. |
| 157 | Orangeburgh | Orangeburgh | 35 30 | 80 50 | | E. to W | | | Prof. R. M. Davis, South Carolina College, Columbia. | Faint rumble and tremor for ten or fifteen seconds as when riding on a tolerably rough railroad; then vibrations as when brakes are put on; then still harder as when a car is bumping on the ties, and then gradually dying away; plastering knocked down and brick walls cracked; shock apparently lighter than at Columbia above or on the road below. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**SOUTH CAROLINA—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | m. | s. | | |
| 158 | Pacolet | Spartanburgh | 34 52 | 81 47 | | | | | G. M. Aultman | Effects as violent as at Spartanburgh. |
| 159 | Pendleton | Anderson | 34 40 | 82 45 | | | | | R. E. Barnwell | Village considerably shaken, but no damage. |
| 160 | Pickens | Pickens | | | | | | | Associated Press | Brought everybody into the street; a loud roaring like a train of cars accompanied the shock, which lasted about three minutes; some plastering fell, but no one injured and no serious damage done; several lighter shocks followed at intervals of a few minutes. |
| 161 | Piedmont | Greenville | | | | | | | C. R. Casilear | Shock felt with considerable force, causing some alarm. |
| 162 | Plantersville | Georgetown | 33 37 | 79 11 | | | | | Charleston Year Book | People left houses, and most of them sat up all night. |
| | do | do | 33 37 | 79 11 | | | | | Miss S. I. Gibbs | |
| 163 | Plum Branch | Edgefield | | | 6 | | 10 | | S. E. Freeland | Six shocks within an hour and a half, each accompanied by sound; in bed; house rocked like a cradle; low rumbling from SW. to NE. Every one rushed out of the house; undulatory. |
| | do | do | | | | | 10 | | Signal Service observer | Shock severe; low, heavy rumbling. |
| 164 | Port Royal | Beaufort | 32 22 | 80 33 | | | | | United Press | The shock very violent, moving houses on the foundations, destroying chimneys, and throwing people to the ground; negroes in a state of frenzy. |
| 165 | Prosperity | Newberry | | | 3 | W. to E. | | | Charleston Year-Book | Distinct shocks between 9.43 and 10.10; shook down some chimneys. |
| | do | do | | | 3 | W. to E. | | | News and Courier, September 4, 1886. | Distinct shocks; shook down some chimneys. |
| 166 | Privateer | Sumter | | | 10 | | | | Charleston Year-Book | First shock severe, lasting one minute, and was followed by tremendous rumblings; the second, fifteen minutes later and of a minute's duration, was even harder than the first. Chimneys badly cracked, and the tops of several were knocked off by the first shock. The first two waves came from the southeast and went northwest. Eight distinct shocks, lasting a few seconds each, followed at intervals of from ten minutes to an hour; these seemed to pass from NE. to SW. |
| 167 | Rattlesnake Shoal Light-ship. | | | | 5 | | | | New York Herald, September 17, 1886. | Shock felt as of collision with another ship. First shock lasted forty-five seconds, and was followed by four others between that time and 4 a.m., each decreasing in force; masts and lamps were severely shaken; a succession of heavy jars. |
| | do | | | | | | | | Light-House Board | Felt shock distinctly; severe jarring sensation; shock came from southward and westward. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**SOUTH CAROLINA—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | m. | s. | | |
| 168 | Ravenels | Colleton | | | | | | | Chicago Inter-Ocean, September 2, 1886. | Railroad under water in some places between here and Charleston. The earth has caved in several places. |
| 169 | Reidsville | Spartanburgh | | | | | | | G. M. Aultman | Effects similar to those at Spartanburgh. |
| 170 | Richland | Oconee | | | | | | | Morning News, September 1, 1886. | |
| 171 | Ridgeway | Fairfield | 34 17 | 80 58 | | | | | J. Bonneau | Effects similar to those at Blythewood. |
| 172 | Rock Hill | York | 34 53 | 81 03 | | | | | Charleston Year-Book | The first shock lasted two minutes; others were felt until 2 a. m.; no serious damage. |
| | do | do | | | | | 2 | | News and Courier, September 4, 1886. | No serious damage. |
| 173 | St. Andrew's Parish | | | | | | | | Florida Times-Union, September 9, 1886. | In St. Andrew's Parish an area 10 miles long is cut up by small fissures and mud-holes of from an inch to 10 feet in diameter, which emit blue mud and gray sand in large quantities, and the whole surface is covered with little mounds. |
| 174 | St. Linian's Light | | | | | | | | Light-House Board | Severe shock; broke flushing pane and stopped clock-work; short vibration. |
| 175 | Saluda Oldtown | Newberry | 34 11 | 81 45 | | | | | A. P. Danks | Effects similar to those at Newberry Court House. |
| 176 | Seneca | Oconee | 35 41 | 82 53 | | | | | G. Markriter | Reported to have been very forcible; creating some alarm. |
| 177 | Society Hill | Darlington | 34 30 | 79 52 | | | | | Western Union Telegraph. | Several severe shocks, the first most violent, driving people from their houses, many fearing to return; chimneys broken and plastering shaken down; several additional shocks during the night, each accompanied by loud roaring, which seemed to die away to the northward. |
| 178 | South Island, Santee River. | | | | | NE. to SW | | | T. E. Hazzard | Awakened from sound sleep by fearful shaking of house and noise as of a heavily-ladened train rapidly approaching; chimney arches were thrown down, and in one instance bricks were shaken off the side and top of a chimney. |
| 179 | Spartanburgh | Spartanburgh | 34 56 | 81 57 | 10 | N. to S | | | Charleston Year-Book | The first and severest shock lasted three minutes, and was preceded by a rolling, rumbling sound, seeming to come from west or northwest; five shocks followed within an hour, lasting from thirty to sixty seconds; four more shocks felt Wednesday morning; the direction being N. and S. as shown by cracked walls; terror, in some cases amounting to wild frenzy, took possession of the people. |

*Report of earthquake observations, earthquake of August 31, 1886*—Continued.

**SOUTH CAROLINA—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | | | | |
| | Spartanburgh | Spartanburgh | 34 56 | 81 57 | | | | | G. M. Aultman | Very severe all over the country; state of people one of great excitement and apprehension; buildings cracked, chimneys broken, plastering thrown down, and objects thrown from mantel and tables. |
| 180 | St. Stephen's | | 33 23 | 79 55 | 7 | | | | Charleston Year-Book | Three severe shocks and four lighter ones. |
| 181 | Statesburgh | Sumter | 34 58 | 80 31 | | | | | Dr. W. W. Anderson | Weight at end of pendulum of a clock was bounced from its hook, which was more than a half inch deep; many chimneys cracked and damaged; but little other damage to buildings; many rushed from houses in alarm. |
| 182 | Steedman's | Lexington | 33 45 | 81 21 | | | | | J. Rowe | Houses considerably shaken, but no serious damage; about ten shocks during the night; the first most violent, and lasting two minutes. |
| 183 | Sullivan's Island Range. | | | | | | | | Light-House Board | Rear beacon shook violently, throwing chimney from lamp. |
| 184 | Summerville | Charleston | 33 04 | 80 11 | | | | | | |
| 185 | Sumter | Sumter | 33 56 | 80 20 | | | | | Charleston Year Book | The people alarmed, and several chimneys demolished. |
| 186 | Timmonsville | Darlington | 34 07 | 79 53 | | | | | Associated Press | Similar effects to those at Florence and Darlington. |
| 187 | Trenton | Edgefield | | | | | | | D. Middleton | Shock very forcible; probably as much so as at Langley, Bath, and Hamburgh. |
| 188 | Triangle | Laurens | | | 6 | | | | | Intervals of about twenty minutes; preceded by considerable noise; first severe; others light. |
| 189 | Tybee Light-house | | | | | | | | Light-House Board | Greatest vibration; lens severely shaken, etc., but no serious damage. |
| 190 | Union | Union | 34 43 | 81 37 | 10 | E. to W | | | Charleston Year Book | Ten distinct shocks between 10 p. m. and daybreak. The vibrations came from nearly due east. There was much alarm, but no damage of consequence. |
| 191 | Varnville | Hampton | 32 52 | 81 02 | | | | | J. Hennessy | The first shock caused the greatest confusion and terror among blacks and almost as much among whites; houses very badly shaken. Several shocks followed, but the consternation was so great that no account was kept of them. |
| 192 | Vaucluse | Aiken | 33 38 | 81 44 | | | | | D. Middleton | Effects similar to those at Langley, Bath, and Trenton. |
| 193 | Vaughnsville | Newberry | | | | | | | A. P. Danks | Effects similar to those at Newberry Court House. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**SOUTH CAROLINA—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | m. | s. | | |
| 194 | Walhalla | Oconee | 34 46 | 83 04 | | | | | Associated Press | Considerable excitement; houses shaken; bricks thrown from chimneys, and clocks stopped; water spilled from tanks; plastering cracked. No serious damage. |
| 195 | Walnut Grove | Spartanburgh | 35 50 | 81 58 | | | | | G. M. Aultman | Effects similar to those generally felt throughout the same county. |
| 196 | Waverly Mills | Georgetown | | | 1 | N. to S | | 30 | W. I. Mazyck | Heavy rumbling, like heavy train of cars in rapid motion. People rushed from houses in alarm. |
| 197 | Westminster | Oconee | | | | | | | G. Markriter | Reported to have been very forcible, creating some alarm. |
| 198 | Williamston | Anderson | 34 38 | 82 29 | | | | | Charleston Year Book | The first and strongest caused some alarm. Four or five shocks were felt before 1 o'clock a. m. and one about 5 a. m. A few bricks fell from old chimneys. The roar sounded like a train of cars. |
| 199 | Willington | Abbeville | 33 56 | 82 27 | | | | | do | A heavy shock, doing great damage to chimneys throughout this section. Some springs have gone dry and some are flowing more freely. |
| 200 | Williston | Barnwell | 33 23 | 81 23 | 12 or 13 | | | | do | People terribly excited. |
| 201 | Winnsborough | Fairfield | 34 22 | 81 07 | | | | | Western Union Telegraph. | Several severe shocks, bringing people out of their houses. Some chimneys dislodged and windows broken. Great excitement and fear, especially among negroes. |
| 202 | Woodruff's | Spartanburgh | | | | | | | G. M. Aultman | Similar to effects generally felt throughout the county. |
| 203 | Woodward | Fairfield | 34 30 | 81 11 | | | | | Western Union Telegraph. | Felt with great force, alarming all people. |
| 204 | Yemassee | Beaufort | 34 40 | 80 50 | | E. to W | | | News and Courier, September 3, 1886. | Distinct shocks. |
| 205 | Yorkville | Yorkville | 34 57 | 81 15 | | | | | | Felt with great severity, causing great excitement. |

**TENNESSEE.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Arlington | Shelby | | | | | 1 | | W. C. Morris | Followed by a rumbling. Observations by himself and Captain Garret. |
| 2 | Athens | McMinn | 35 27 | 84 33 | | | | | Knoxville Journal, September 1, 1886. | Heavy shock, frightening the people. |
| 3 | Benton | Polk | 35 42 | 84 36 | 2 | | 2 to 5 | | L. W. Hildebrand, postmaster. | |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**TENNESSEE—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | *m.* | *s.* | | |
| 4 | Blountville | Sullivan | 36 32 | 82 20 | 1 | | | | H. H. Masengill | Not felt on high ground; windows upstairs shook, but not felt in my room. |
| 5 | Bolivar | Hardeman | 35 16 | 89 00 | 1 | SW. to NE | | 2 | Signal Service observer. | Undulatory; felt by one-third the people; felt all over the city; no noise Firm, high ground. |
| 6 | Bristol | Sullivan | 36 36 | 82 10 | | | 1 | | Knoxville Journal, September 1, 1886. | Felt. Considerable excitement. |
| | do | do | 36 36 | 82 10 | | | 10 | | J R. Boyd, manager Western Union Telegraph Company. | Information from hotel register. |
| 7 | Brownsville | Haywood | 35 36 | 89 16 | 3 | SE. to NW | | 7 | Signal Service observer. | Duration, about seven and one-half seconds each; generally felt; a tremor; many felt dizziness. |
| 8 | Caryville | Campbell | 36 15 | 84 10 | 2 or 3 | | | | R. Fowler | Duration, several minutes; accompanied by rumbling; crockery and ornaments moved and broken by falling; plastering cracked: intensity strong. |
| 9 | Celina | Clay | 36 31 | 85 29 | 2 | | | | New Orleans Democrat, September 3, 1886. | Duration, one minute each; interval, twenty minutes; houses vibrated. |
| 10 | Chattanooga | Hamilton | 35 03 | 85 16 | | | | 20 | Associated Press | Gas lights in stone building swayed; windows shook; considerable excitement prevailed. |
| | do | do | 35 03 | 85 16 | | | | 3 | New York Times, September 1, 1886. | Houses quaked perceptibly and the rumbling was very distinct. People rushed to the streets. |
| | do | do | 35 03 | 85 16 | | E. to W | | 20 | Chattanooga Daily Times, September 1, 1886. | A mighty jar, followed by rocking of buildings; chandeliers swung violently and windows rattled; accompanied by low rumbling; people left houses. |
| | do | do | 35 03 | 85 16 | | | | | Hon. H. M. Wiltsee | Strong; overturning chimneys in some cases. |
| | do | do | 35 03 | 85 16 | 2 | | | | Signal Service observer. | Duration, each shock three minutes; interval, thirteen minutes; no noise; slight near the surface and moderate in third and fourth stories. |
| 11 | Chestnut Mound | Smith | 36 11 | 85 47 | 2 | | 1 | | New Orleans Times-Democrat, September 3, 1886. | Duration, one minute each; interval, twenty minutes; houses vibrated. |
| 12 | Clarksville | Montgomery | 31 31 | 87 20 | 2 | | 1 | | New Orleans Democrat, September 3, 1886. | Duration, one minute each; interval, twenty minutes; houses vibrated. |
| 13 | Cookeville | Putnam | 36 07 | 85 32 | 2 | | 1 | | do | Duration, one minute each; interval, twenty minutes; houses vibrated. |
| 14 | Covington | Tipton | 35 32 | 89 40 | 1 | | | | W. N. White | Duration, a few seconds; oil in lamp and chandeliers swayed; light; no noise. |
| 15 | Dayton | Rhea | 35 29 | 84 58 | 2 | NW. to SE | | | W. H. C. Brown | No noise. Second followed quickly and was a mere vibration. Cradle rocked; no damage. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**TENNESSEE—Continued,**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | *m.* | *s.* | | |
| 16 | Dowelltown | De Kalb | 35 58 | 84 56 | 2 | | 1 | | New Orleans Democrat, September 3, 1886. | Duration, one minute each; interval, twenty minutes; houses vibrated. |
| 17 | Dyersburgh | Dyer | 36 01 | 89 24 | 2 | SSW. to NNE. | | 5 | Louis Hughes | Total duration about five seconds. On ground floor, frame house, clay foundation; regulator clock on north and south wall not affected. |
| 18 | Embreeville | | | | | | | | B. Willis | Ten miles above, on river, in tent on sand-bar. Several heard a distant rumbling, and those sitting on heavy articles, as a trunk, felt a slight jar. Recognized as an earthquake in a frame house close by. |
| 19 | Gainesborough | Jackson | 36 19 | 85 58 | 2 | | 1 | | New Orleans Democrat, September 3, 1886. | Duration, one minute each; interval, twenty minutes; houses vibrated. |
| 20 | Gordonsville | Smith | 36 10 | 85 56 | 2 | | 1 | | do | Duration, one minute each; interval, twenty minutes; hhouses vibrated. |
| 21 | Grand Junction | Hardeman | 35 02 | 89 14 | | | | | J. B. Irwin | No noise. Sand, over firm red clay. |
| 22 | Granville | Jackson | 36 15 | 85 46 | 2 | | 1 | | New Orleans Democrat, September 3, 1886. | Duration, one minute each; interval, twenty minutes; houses vibrated. |
| 23 | Greeneville | Greene | 36 20 | 82 50 | | | | | Knoxville Journal, September 1, 1886. | Severe shock; intense excitement; people rushed into the streets. |
| | do | do | 36 10 | 82 50 | | S. to N. | 1 | | B. Willis | Seated in frame house on solid limestone hill. A loud rumbling, accompanied by a heavy jar. Furniture shook; rocking-chairs rocked, and student's lamp rattled violently; family alarmed. Other families in neighborhood frightened from houses; ladies felt vertigo. |
| 24 | Humboldt | Gibson | 35 49 | 88 56 | 2 | | | 20 | W. H. Stillwell, M. D. | Total duration, about twenty seconds; a low indistinct sound. |
| 25 | Huntingdon | Carroll | 35 58 | 88 23 | | | | | New Orleans Democrat, September 3, 1886. | Houses severely shaken. |
| 26 | Jamestown | Fentress | 36 24 | 84 55 | 2 or 3 | | 2 | | H. B. Morgan | Strongly felt; intensity "moderate." |
| 27 | Knoxville | Knox | 35 56 | 83 58 | 3 | E. to W. | | 50 | Associated Press | First interval seven minutes; second four minutes; glass rattled and buildings shook; people rushed to the streets, greatly frightened. Third shock very light. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**TENNESSEE—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | *m.* | *s.* | | |
| | Knoxville | Knox | 35 56 | 83 58 | 3 | E. to W | | | Knoxville Journal, September 1, 1886. | Duration first shock four minutes; interval, five minutes; second shock severest; felt all over city; especially felt in upper stories of brick buildings; windows rattled; tables and chairs shook; buildings rocked, and inmates rushed wildly to the streets. Felt decidedly in the hotels; moving furniture, rattling mirrors, and frightening guests. In club-rooms, on third story, new building, walls and plastering cracked, and building was considerably damaged. A number of meetings were broken up. Very severe in West End and Mechanicsville. Least severe in North Knoxville. Felt by almost every one. |
| | do | do | 35 56 | 83 58 | 3 | E. to W | | | Signal Service observer. | Duration first shock one minute; second and third, thirty seconds each, preceded by low rumbling; light; no serious damage· buildings rocked east and west. |
| 28 | Lexington | Henderson | 35 38 | 88 24 | 2 | | | 6 | S. A. Mynders, principal Lexington Academy. | No noise. |
| 29 | Manchester | Coffee | 36 26 | 86 03 | | | | | New Orleans Democrat, September 3, 1886. | Glasses in church broken. |
| 30 | Memphis | Shelby | 35 09 | 90 07 | 1 | N. to S | | 10 | Associated Press | Violent shock; a rapid oscillating; many fled to the streets, numbers in night dress; guests at Peabody Hotel rushed down-stairs; many women went into hysterics; equally severe all over the city. |
| | do | do | 35 09 | 90 07 | 2 | | | 20 | D. F. Flannery, sergeant Signal Service. | Shocks about equal in intensity; total duration, about twenty seconds, including interval of one or two seconds. |
| | do | do | 35 09 | 90 07 | 1 | | | | E. Lippincott, M. D | Experienced observer; but one shock. |
| | do | do | 35 09 | 90 07 | 2 | E. to W | | 25 | W. Harvey, chief operator (Western Union Telegraph Company). | Interval, fifteen; no noise; no electrical disturbance; E. to W. (as shown by a number of observations). |
| | do | do | 35 09 | 90 07 | | | | | Bro. Maurelian, president Christian Brothers' College. | |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**TENNESSEE—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | m. | s. | | |
| 31 | Milan | Gbison | 35 54 | 88 47 | 2 | SSW. to NNE. | | | O. F. Cantwell | Duration first shock, one minute; second, twenty-five seconds; rolling country; thin soil over clay and sand; very generally felt in buildings; some were awakened; at table, facing south; table rose 2 or 3 inches, self and chair thrown backwards; west end of table rose a little higher than east end; clerk in same building, on south side of desk, was thrown forward; no damage save cracked plastering. |
| 32 | Murfreesborough | Rutherford | 35 49 | 86 24 | 2 | | | 2 | F. White (postmaster?) | No noise. |
| 33 | Nashville | Davidson | 36 09 | 86 45 | 2 | | | | Associated Press | Distinct shocks; interval, three minutes; very perceptible in tall buildings, but not felt by a majority of people. |
| | do | do | 36 09 | 86 45 | 3 | W. to E. | | | Nashville Chronicle, September 1, 1886. | In Chronicle office, on third floor; it shook walls and floors, rattled windows, and caused nausea; everybody rushed out of doors; no damage save breaking of a few panes of glass and cracking of plastering; first shock violent, lasting possibly forty seconds; a tremor, changing to distinct vibrations; second and third barely felt, and lasting thirty seconds each; intervals, seven and six minutes respectively; the signal officer says duration of each shock thirty seconds, and direction E. to W. |
| 34 | Newport | Cocke | 35 58 | 83 12 | | | | | Knoxville Journal, September 1, 1886. | Severest ever known in community. |
| 35 | Paris | Henry | 36 16 | 88 20 | 1 | SW. to NE. | | 30 | E. P. Wood and C. A. Davies. | No noise; duration, about thirty seconds; ground, a red clay; in second story of depot hotel; continued oscillations. |
| | do | do | 36 16 | 88 20 | 2 | do | | | J. P. Chambers | Total duration, about one minute; heavy rumbling; houses shook considerably; doors and pictures swung; people nauseated; ground, level and of clay; animals frightened. |
| 36 | Pulaski | Giles | 35 14 | 87 02 | | | | | New Orleans Democrat, September 3, 1886. | Houses severely shaken. |
| 37 | Rogersville | Hawkins | 36 25 | 83 00 | 2 | SE. to NW. | | | S. P. Powel, postmaster. | Duration first shock, one minute; second, one-half minute; first shock moderate, second light; upstairs, lying down; short, abrupt waves; shook bed from SE. to NW.; some heard roaring; plastering cracked in several buildings, windows rattled, and light objects thrown down; town on clay over slate and limestone strata. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**TENNESSEE—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | m. | s. | | |
| 38 | Saulsbury | Hardeman | 35 02 | 89 08 | 1 | E. to W | | 20 | R. M. Bostwick, M. D | Undulatory. |
| 39 | Shelbyville | Bedford | 35 29 | 86 24 | | | | | New Orleans Democrat, September 3, 1886. | Houses severely shaken. |
| 40 | Smithville | De Kalb | 35 56 | 85 48 | | | | | New Orleans Democrat. | People left houses. |
| 41 | Sneedville | Hancock | 36 31 | 83 12 | 1 | | ½ | | L. M. Jarvis, postmaster. | Accompanied by roaring; felt by a majority; rattling windows and crockery; very heavy; made houses vibrate; no damage. |
| 42 | Sweet Water | Monroe | 35 37 | 84 26 | | | | | Knoxville Journal, September 1, 1886. | A severe shock. |
| 43 | Tracy City | Grundy | 35 18 | 85 44 | | W. to E | | | W. J. Thomas, postmaster. | |
| | ......do | ....do | 35 18 | 85 44 | 1 | ....do | | | Signal Service observer | |
| 44 | Tullahoma | Coffee | 35 20 | 86 09 | | | | | New Orleans Democrat, September 3, 1886. | Houses swayed; inmates awakened; violent trembling. |
| 45 | Whitman | Campbell | 36 16 | 84 25 | | | | | Savannah News, September 3, 1886. | Slight; windows rattled considerably; brick stores very generally shaken. |
| 46 | Winchester | Franklin | 35 25 | 86 03 | | | | | New Orleans Democrat, September 3, 1886. | Houses severely shaken. |

**VERMONT.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Bellow's Falls | Windham | | | 1 | | | | H. Wells | One in the family noticed it at 9.53; picture-frames rattled; a loosely-fitting spigot in a bath-tub was shaken from its place; the residence where it was noticed stands 500 or 600 yards from the river and 300 feet above it. |
| 2 | Brattleborough | ....do | | | 1 | | | | W. M. Davis | Distinctly felt about 10 p. m. |
| 3 | Bridport | Addison | | | | | | | ......do | Not felt. |
| 4 | Burlington Light-house. | | | | | | | | James Wakefield | Light-house; not felt. |
| 5 | Burlington | Chittenden | | | | | | | G. H. Howard | Not felt. |
| 6 | ......do | ....do | | | | | | | W. M. Davis | Was said to have been felt, though by only a few, and not spoken of until after news of the earthquake had been received. |
| 7 | Chelsea | Orange | | | | | | | H. L. Bixby | Not felt. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**VERMONT—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | m. | s. | | |
| 8 | Cornwall | Addison | | | | | | | W. M. Davis | Not felt. |
| 9 | Hartland Four Corners | Windsor | | | | | | | B. P. Ruggles | Do. |
| 10 | Isle La Motte | | | | | | | | W. F. Hill | Light-house; not felt. |
| 11 | Leicester | Addison | | | | | | | O. H. Norton | Not felt, so far as known to him, except a slight jar at Burlington. |
| 12 | Lunenburgh | Essex | | | | | | | W. M. Davis | Not felt. |
| 13 | Middlebury | Addison | | | | | | | L. E. Knapp | Do. |
| 14 | Newport | Orleans | | | | | | | W. M. Davis | Do. |
| 15 | Pownal | Bennington | | | | | | | do | Do. |
| 16 | Rutland | Rutland | | | | | | | H. M. Downs | Do. |
| 17 | Sharon | Windsor | | | | | | | E. K. Baxter | Do. |
| 18 | St. Johnsbury | Caledonia | | | | | | | E. H. Walcott | Distinctly felt, and commented upon early on Wednesday morning before any news of the earthquake had been received; slight shock, merely rattling dishes in the pantry, and causing comment among the few who noticed it. |
| 19 | Windmill Point | | | | | | | | H. C. Phelps | Light-house; not felt. |

**VIRGINIA.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | m. | s. | | |
| 1 | Abingdon | Washington | | | | | | | Lynchburgh Virginian, September 2, 1886. | Plastering dislodged in several houses and inmates much excited. |
| 2 | Alden | King George | 38 16 | 77 05 | 1 | | | | C. H. Ashton | Clock stopped. |
| 3 | Alexandria | Alexandria | 38 48 | 77 03 | | | | | New York Sun, September 2, 1886. | Houses shook, clocks stopped, and people ran into the streets in night clothes. |
| | do | do | 38 48 | 77 03 | | | | 10 | L. J. Walsh | A party at cards; cards shaken off the table; man in bed upstairs was alarmed by shaking of house. |
| 4 | Alleghany Spring | Montgomery | 37 11 | 80 17 | | | | | Richmond Whig, September 3, 1886. | Felt by many guests; plastering of a brick dwelling shaken down. |
| 5 | Ashcake | Hanover | 37 39 | 77 21 | 2 | | 1 | | Richmond State, September 1, 1886. | Duration first shock, about one minute; after sixteen minutes second shock, barely perceptible; piano and beds moved 6 inches; everything loose moved. |
| 6 | Assateague Light-station. | | | | 2 | | | | No name | Duration first shock, fifteen seconds; interval, ten minutes; no noise; seemed like a tremor. |
| 7 | Big Springde Dot | Montgomery | 37 15 | 80 18 | | | | | Lynchburgh Virginian, September 2, 1886. | Felt. |

*Report of earthquake observations, earthquake of August 31, 1886*—Continued.

**VIRGINIA—Continued.**

| No. | Locality. | County. | Latitude. ° ′ | Longitude. ° ′ | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| 8 | Black Water | Lee | | | 3 | | | | Richmond Whig | Family awakened by severe shaking and trembling of house, which lasted about one-half a minute; at intervals of five minutes, two slight shocks followed; generally felt. |
| 9 | Bristoe | PrinceWiliiam | | | | | | | Lynchburgh Virginian, September 2, 1886. | "A general shake-up." |
| 10 | Buchanan | Botetourt | 37 31 | 79 42 | 2 | | | | Richmond State, September 1, 1886. | Interval, about fifteen minutes; first shock severest; windows and doors rattled and furniture was shaken. |
| 11 | Buffalo Lithia Springs | Mecklenburgh | 36 39 | 78 39 | 5 | | | | Richmond Whig, September 3, 1886. | Distinct shocks; duration first shock, over one minute. |
| 12 | Byrdsville | Pittsylvania | | | 4 | | | | Danville Register, September 2, 1886. | Family awakened by a noise like a rushing wind; doors of safe opened and whole house rattled; duration first shock, one and one-half minutes; interval, fifteen minutes each; second and third shocks very severe, but no noise; fourth, interval thirty minutes. |
| 13 | Cape Charles Light-house. | | | | 2 | SW. to NE. | | | J. Goffiga, keeper | Duration first shock, fifteen seconds; second, ten seconds, preceded by noise as of persons coming up the tower; tower vibrated; suspended objects swung considerably; not noticed by those in bed in dwellings; interval, fifteen minutes. |
| 14 | Cape Henry Light-station. | | | | 1 | | | | M. L. Odell, keeper | Accompanied by a distant rumbling; was awakened; window-weights jarred loudly; undulatory; light grew dim; strong pane of glass slightly broken. |
| 15 | Cascade | Pittsylvania | 36 34 | 79 25 | | | | | Danville Register, September 2, 1886. | Severe shock. |
| 16 | Charlottesville | Albemarle | 38 02 | 78 28 | | | | | W. H. Ireland | "Heard that several chimneys were overthrown." |
| 17 | Chatham | Pittsylvania | 36 49 | 79 25 | 3 | | | | C. A. Douglass, telegraph operator. | Duration first shock, one to one and one-half minutes; first interval, fifteen or twenty minutes; at desk, writing; heard rumbling and went outside; ground had undulatory motion; third shock very light. |
| | do | do | 36 49 | 79 25 | | | 1 | | Lynchburgh Virginian, September 1, 1886. | "Violent shock." |
| 18 | Chincoteague Island | Accomack | | | | | | | Sergeant A. B. Crane, Signal Service. | Shock felt in tower of Assateague Light-house, but by few elsewhere along coast as far as Ocean City. |
| | do | do | | | 1 | | | 10 or 15 | Signal Service observer | Slight noise. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**VIRGINIA—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | m. | s. | | |
| 19 | Churchland | Norfolk | 36 50 | 76 22 | | | | | Norfolk Virginian | Wildest excitement. |
| 20 | Clifton Forge | Alleghany | 37 46 | 79 52 | | | | | Associated Press | Severe earthquake; great excitement. |
| 21 | Columbia | Fluvanna | 37 46 | 78 11 | 2 | | | | W. Nelson | Interval, two minutes; duration, one-half to one minute; preceded by rumbling; house on hill near river; shock distinctly felt by every one in house; beds rocked and windows rattled. |
| | ......do | ....do | 37 46 | 78 11 | 2 | | | 20 | R. E. Nelson | Accompanied by rumbling; two shocks, with continuous vibrations. |
| 22 | Daggers Springs | Botetourt | 37 41 | 79 50 | | | | | Dr. A. Taylor | House shook; felt by several in different cottages. |
| 23 | Dale Enterprise | Rockingham | 38 25 | 78 59 | | E. to W | | | L. J. Heatwall | Duration, several seconds. |
| | ......do | ....do | 38 25 | 78 59 | | ...do | | | Signal Service observer | Decided shock. |
| 24 | Danville | Pittsylvania | 36 34 | 79 25 | 2 | | | | Associated Press | Slight shock; second, very slight; buildings shook and inmates rushed to the streets. |
| | ......do | ....do | 36 34 | 79 25 | | | | | Danville Register, September 2, 1886. | Houses swayed, bricks fell from chimneys, walls cracked, and door-bells rang; a chandelier swung for eight minutes after shock; one party says four shocks, at intervals of thirteen, seven, and twenty-three minutes, respectively. |
| | ......do | ....do | 36 34 | 79 25 | | | | | Prof. W. M. Chauvenet. | Twenty miles NE. of Danville distinctly felt; ornaments thrown down, pictures displaced, and china broken. |
| 25 | Eastville | Northampton | 37 22 | 75 56 | | | | | W. A. Thom, M. D | Not felt by own family, but distinctly felt by neighbors. |
| | ......do | ....do | 37 22 | 75 56 | | | | | S. S. Nottingham | Undulatory; duration, a few seconds; several felt nausea; suspended objects swung; accompanied by roaring. |
| 26 | Emory College | | | | | | | | Lynchburgh Virginian, September 2, 1886. | Students left building; ladies fainted; people were generally frightened. |
| 27 | Estillville | Scott | | | 1 | W. to E | | 20 | W. F. Edwards, postmaster. | Rumbling noise; felt by majority; rattling of windows, doors, and crockery; many awakened. |
| 28 | Fairfax Court House | Fairfax | 38 49 | 77 18 | 1 | | 1 | | J. Hawxhurst | Very sensibly felt by most persons; windows and crockery rattled; bed shook (in second story); horizontal and undulatory. |
| 29 | Fortress Monroe | Elizabeth City | 76 16 | 37 00 | | | | | | |
| 30 | Franklin City | Southampton | | | | | | | New York World | |
| 31 | Fredericksburgh | Spottsylvania | 38 19 | 77 27 | 2 | E. to W | | 60 | G. R. Fitzhugh | Reading in second story, brick building; floor quivered; doors and windows rattled; pictures swayed from E. to W.; second shock light and ten minutes after. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**VIRGINIA—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | | | | |
| 32 | Glade Spring | Washington | 36 49 | 81 52 | | | | | Lynchburgh Virginian, September 2, 1886. | People very much excited. |
| 33 | Harrisburgh | Charlotte | | | 2 | E. to W | | | Florida Times-Union, September 2, 1886. | Distinct shocks; people awakened; interval, fifteen minutes. |
| 34 | Harrisonburgh | Rockingham | 38 27 | 78 50 | | | | | New York Sun, September 2, 1886. | |
| 35 | Hillsville | Carroll | 36 42 | 80 49 | | | | | H. H. Farmer, postmaster. | Was felt. |
| 36 | Hog Island Light-station. | | | | | | | | G. W. Doughty, keeper | Slightly felt by a few; I did not feel it. |
| 37 | Hot Springs | Bath | 38 02 | 79 54 | | | | | Postmaster | Not felt. |
| 38 | Jamestown | James City | 37 13 | 76 45 | | | | | Lynchburgh Virginian, September 1, 1886. | Severely felt; people rushed to the streets and nausea is reported. |
| 39 | Jonesville | Lee | 36 42 | 83 07 | 3 | | | | C. Willoughby, deputy United States marshal. | Shocks of decreasing intensity; duration first shock, fifteen seconds; cracked plastering, threw bricks from chimney of court-house, broke window panes, and caused general consternation. |
| 40 | Lexington | Rockbridge | 37 47 | 79 28 | 3 | | | | Lynchburgh Virginian. | First two very heavy, third slight; people very generally awakened; shocks in close succession. |
| 41 | Killick Shoal Light-house, Chincoteague Island. | | | | 1 | E. to W | 10 | | W. M. Parker, keeper | House on iron piles; motion vertical; hanging objects swung E. to W.; door in wall running N. to S. opened. |
| 42 | Lunenburgh Court House. | Lunenburgh | 36 58 | 78 13 | 2 | | 1 | | M. C. Cardozo, postmaster. | Interval, ten minutes; "light;" roaring. |
| 43 | Lynchburgh | Campbell | 37 25 | 79 09 | 1 | | 1 | | Associated Press | Very pronounced; houses swayed, chandeliers shaken, bricks thrown from chimneys, and many sleepers frightened to the streets; accompanied by heavy rumbling. |
| | ...do | ...do | | | 1 | | 2 | | Lynchburgh Virginian, September 1, 2, 1886. | Beds moved, windows rattled violently, bricks shaken from chimneys, walls cracked in several houses, some people awakened, and many frightened to the streets. Much heavier on hills than level streets. |
| 44 | Madison | Madison | 38 23 | 78 15 | | | | | Lynchburgh Virginian. | Was felt; some were badly frightened. |
| 45 | Manchester | Chesterfield | 37 32 | 77 25 | 2 | | | | Richmond State, September 1, 1886. | Violent shocks reported by farmers. One reports plastering cracked and brick shaken from chimney. |
| 46 | Marion | Smyth | 36 52 | 81 36 | 2 | NW. to SE | | | Anonymous | Very short duration; no noise; windows and doors rattled; felt by almost every one. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**VIRGINIA—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | m. | s. | | |
| 47 | Martinsville | Henry | 36 43 | 79 55 | 4 | | | | Danville Register, September 2, 1886. | First heaviest and lasted one minute; considerable alarm. |
| 48 | Natural Bridge | Rockbridge | 37 37 | 79 36 | | | | | Lynchburgh Virginian, September 1, 1886. | "Severe." |
| 49 | New Store | Buckingham | 37 26 | 78 36 | 3 | N. to S. | | | Richmond Whig, September 3, 1886. | Distinct shocks; first heaviest and lasted about two minutes; intervals, ten and twenty minutes respectively; undulatory; great excitement; not felt at a point 3 miles NW., nor at another 5 miles NE., but was severe S. to SE. |
| 50 | Norfolk | Norfolk | 36 51 | 76 15 | 2 | | 1 | 30 | Associated Press | First heaviest, and lasted one and one-half minutes. |
| | do | do | 36 51 | 76 15 | 1 | E. to W | | | Washington Post, September 1, 1886. | Rattled windows. |
| | do | do | 26 51 | 76 15 | 1 | N. to S. | | 16 | Richmond Whig, September 1, 1886. | Distinct shock, ringing bells, upsetting pitchers, waking people, and frightening many to the streets. Much excitement at the theaters and on the streets. |
| | do | do | 36 51 | 76 15 | 2 | S. to N. | 1 | 30 | Norfolk Virginian, September 1, 1886. | First "severe," and lasted one and one-half minutes. Work in printing offices suspended, bells rung, and people frightened to the streets. Confusion in the jail and almost a panic at Opera-house. Great excitement in west end and southern and eastern parts of city, but hardly felt in northern parts. A second and lighter felt twenty-three minutes later. |
| | do | do | 36 51 | 76 15 | | | | | Anna P. Smith | Terrible rumbling, followed instantly by tremor, increasing to undulations; trees rustled; scarcely felt by people walking. |
| | do | do | 36 51 | 76 15 | 2 | S. to N. | | | Sherry, sergeant | Well-marked shock; second and lighter twenty-three minutes later. |
| | do | do | 36 51 | 76 15 | 3 | | | 36 | J. H. Tierney | Like a heavy wagon; starting at a point S. or SW. |
| 51 | Old Point Light-house. | | | | | | | | J. B. Jones | |
| 52 | Petersburgh | Dinwiddie | 37 15 | 77 22 | 1 | | | | Associated Press | Houses rocked, windows rattled, and people rushed to the streets; great excitement. |
| | do | do | 37 15 | 77 22 | 1 | | | 2 | New York World, September 1, 1886. | Severe, and felt in all sections of city; houses shook, people awakened, and articles shaken from mantels. |
| | do | do | 37 15 | 77 22 | | | | | Norfolk Virginian, September 2, 1886. | Window-panes shattered in several houses; not noticed by most people. |
| 53 | Point of Shoals Light-house. | Isle of Wight | 34 04 | 76 37 | 3 | | | | T. H. Curtis, keeper | Distinct shocks; first, very heavy; second, lighter; third, very light; intervals three minutes each. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**VIRGINIA—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | m. | s. | | |
| 54 | Pungoteague | Accomack | 37 39 | 75 48 | 1 | E. to W | | 10 | F. H. Ireland | Pictures on E. and W. walls swung; rocking-chair sitting E. to W. rocked. |
| 55 | Rappahannock Station. | Fauquier | 38 33 | 77 49 | 2 | | | | W. H. Ireland | Duration, about one-half minute; house on slate foundations, rock strata, 3 feet under ground; undulatory, accompanied by roaring. |
| 56 | Richmond | Henrico | 37 33 | 77 24 | | | | | Associated Press | Generally felt throughout the city; excitement intense; people thrown from their feet and frightened to the streets; bricks shaken from houses and loose objects from mantels. Wildest excitement at the State prison; prisoners terror-stricken; military called out. |
| | do | do | 37 33 | 77 24 | | | | | Richmond State, September 1, 1886. | Severe shock, followed quickly by lighter one; generally felt in every part of city; most severe in extreme N. and W., and least severe in lower part. Between State-house and Fourteenth street, E. to W., and undulatory. Houses swayed, windows and furniture rattled, plastering and chimneys thrown down, lamps overturned, and pictures shaken violently; some persons rolled from bed and a few nauseated. Entire population in the streets. A meeting broken up. Not felt at a lawn social or the Salvation Army. The wildest excitement at the State prison; prisoners terror-stricken and twelve or fifteen broke through cells; military was called out. |
| 56 | Richmond | Henrico | 37 33 | 77 24 | | | | | Richmond Whig, September 1, 1886. | Felt only in certain localities. Not felt on first floor Whig building; shook considerably on fourth floor. Disturbed guests on upper floors of hotels; not generally felt on ground floors. Very sensibly felt in western parts of city; buildings swayed and chimneys thrown down; great excitement and fear among prisoners; military called out, etc. |
| 57 | Rockingham Springs. | Rockingham | | | | | | | No name | Not felt. |
| 58 | Ruther Glen | Caroline | 37 55 | 77 24 | 2 | | | | Richmond State, September 1, 1886. | Severe shocks; loose articles shaken from mantels. |
| 59 | Smithville | Charlotte | 37 04 | 78 38 | 3 | S. to N | | 2 | B. P. Eggleston, postmaster. | Duration of each, two seconds; total duration, fifteen or twenty minutes. Rumbling and roaring; house shook S. to N.; vibration and tremor. |
| 60 | Spottsylvania | Spottsylvania. | 38 13 | 77 34 | 3 | | | | New York Sun, September 3, 1886. | Rumbling. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**VIRGINIA—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | m. | s. | | |
| 61 | Stuart | Patrick | | | | | | | Danville Register, September 2, 1886. | Bricks thrown from court-house and the bell rung. |
| 62 | Suffolk | Nansemond | 36 44 | 76 33 | | | | | Richmond Whig, September 1, 1886. | Great excitement; people rushed into the streets. |
| 63 | Trenton Mills | Cumberland | 37 38 | 78 15 | 2 | | | | C. S. Dabney | Felt 4 miles southwest of Trenton Mills; accompanied by rumbling; light, but felt by majority; rattled crockery and windows. |
| 64 | Williamsburgh | James City | 37 17 | 76 40 | 2 | | | | Richmond State, September 1, 1886. | Distinct shocks; first, very severe and lasted about twenty seconds; second, lighter. Many rushed into the streets; no serious damage. |
| | do | do | 37 17 | 76 40 | 1 | | | | Norfolk Virginian | "Considerable shock;" great excitement; no serious damage. |
| 65 | Winchester | Frederick | 39 12 | 70 08 | 3 | | | 16 | C. S. Hart | Interval, four to six seconds. In second story, two-story brick house, west room; was awakened, as were others in the house; looking-glass on east and west wall shook; windows and doors rattled; first vertical, then lateral; felt by many. |
| 66 | Wise Court House | Wise | 37 05 | 82 34 | 1 | | | | W. S. Nottingham, postmaster. | Felt by majority; windows and crockery rattled; distant rumbling; "light." |
| 67 | Woodford | Caroline | 38 07 | 77 22 | | E. to W. | | | J. Washington | Doors shook violently; sat in bed and felt swaying; only one on farm felt it. |
| 68 | Woodstock | Shenandoah | 38 53 | 78 30 | | | | | Postmaster | Duration, one to three minutes; felt on high ridge west; not felt on ridge one-fourth mile east, nor in center of town. |
| 69 | Wytheville | Wythe | 36 57 | 81 10 | | SE. to NW | | | H. Shriver | Was seated at transit instrument; body swayed; transit-house rocked slightly; lady felt bed shake and house tremble. |
| | do | do | 36 57 | 81 10 | 3 | | | | J. W. Morehead | Distinctly felt three shocks at momentary intervals; only one of the family awakened; distant rumbling; horizontal and undulatory. |
| | do | do | 36 57 | 81 10 | 2 | | | | Associated Press | "Severe" shocks; first and heaviest lasted three minutes, and swayed buildings, shook down mantel ornaments, awakened sleepers—some rushing out in night clothes; quite general; considerable excitement; second, shortly after first. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**WEST VIRGINIA.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
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| | | | ° ′ | ° ′ | | | | | | |
| 1 | Barbonrsville | Cabell | 38 27 | 82 24 | 2 | SE. to NW | | | H. J. Samuels | On first floor; undulatory and preceded by noise; fifteen or twenty minutes later was in bed and felt second shock, which lasted forty or fifty seconds; bed swayed; some felt dizzy and one lady was nauseated. |
| 2 | Bias | Boone | | | | | | | C. R. Moore | South room, second story, frame house, set N. and S., brick foundation; daughter felt shock; direction, from the SE.; not felt in north room; party in bed in another house was rolled toward the west. |
| 3 | Braxton Court House. | Braxton | 38 39 | 80 48 | 1 | E. to W | | 5 or 6 | J. W. Humphreys | "Light;" felt by majority; rattling a few windows; no noise. In chair, first story, face toward the southwest; horizontal and undulatory; not recognized as an earthquake. |
| 4 | Buckhannon | Upshur | 38 57 | 80 16 | 3 | | | | R. D. Long | First most severe and lasted thirty seconds; dishes shaken from shelves, clocks stopped, bird-cages swung, and doors jarred; people on the street felt sick. |
| 5 | Charleston | Kanawha | 38 21 | 81 40 | 1 | | | 3 | Associated Press | Very severe; many left houses; a number of chimneys toppled over; great excitement. |
| 6 | Grafton | Taylor | 39 18 | 80 03 | | | | | Wheeling Intelligencer, September 1, 1886. | A trembling; houses shook; many alarmed. |
| 7 | Huntersville | Pocahontas | | | 2 | | | 20 | A. Barlow, postmaster | Chandeliers shaken and a few clocks stopped. |
| 8 | Huntington | Cabell | 38 27 | 82 32 | | | | | News—"slip" | Honses swayed, people rushed out, and children screamed. |
| 9 | Logan C. H. | Logan | 35 57 | 82 04 | 2 | | | | J. B. Buskirk, postmaster. | First most severe and lasted about one minute; rumbling; interval, about five minutes. |
| 10 | Madison | Boone | 38 08 | 81 51 | 2 | | 5 | | W. C. Hopkins, postmaster. | Interval, about three minutes; forcibly felt by all; doors and windows rattled; house creaked; all sleepers awakened; horizontal and tremulous; no undulating. |
| 11 | Martinsburgh | Berkeley | 39 27 | 77 55 | | | | | W. B. Colston, postmaster. | Soil clay, rock-ribbed limestone crops out in ledges; was upstairs and did not feel shock. |
| 12 | Moundsville | Marshall | 39 53 | 80 49 | | | | | Wheeling Intelligencer, September 1, 1886. | Very severe; broke windows. |
| 13 | Mouth of Pigeon | Logan | 37 56 | 82 25 | | W. to E | | | M. H. Waldron, M. D. | Two-story frame house, stone foundation; house swayed violently; lamps broken; second shock not half so severe; chimneys toppled off even with the roofs; very severe. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**WEST VIRGINIA—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
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| | | | ° ′ | ° ′ | | | | | | |
| 14 | Nicholas | Nicholas | 38 20 | 80 49 | 1 | | | 40 | H. Templeton, postmaster. | No noise; felt by inmates of hotel and others. (Information from others.) |
| 15 | Parkersburgh | Wood | 39 15 | 81 39 | | | | | Wheeling Register, September 2, 1886. | Very heavy shock; houses shaken, pictures thrown from walls and mantels, people in bed rocked, doors slammed, windows rattled; many left houses, some were nauseated. |
| 16 | ...do | ...do | 39 15 | 81 39 | | | | | W. H. Walker | Five persons, on third bench back from river, say three shocks; first, quite sharp and the most severe; intervals, ten and five minutes, respectively; one shock felt on river bank; brick buildings shook, timbers creaked, chimney thrown down, and people thoroughly frightened; undulatory; most severe on high ground away from river. |
| 17 | Peeryville | McDowell | 37 26 | 81 55 | 2 | | | | J. F. Johnson, postmaster. | Duration, two to five minutes; very light; noticed by a few; no noise. |
| 18 | Petersburgh | Grant | 39 01 | 79 04 | 1 | | | 10 or 15 | E. A. Harness | Possibly a second and lighter. In bed, second story, frame house; windows rattled, house and bed vibrated; felt by very few; soil, sandy loam. |
| 19 | Philippi | Barbour | 39 05 | 80 07 | 2 | | | 15 | D. W. Gall, postmaster | Upstairs. |
| 20 | Point Pleasant | Mason | 38 52 | 82 12 | | | | | Cincinnati Enquirer, September 1, 1886. | Many left hotel; prisoners begged to be released. |
| 21 | Princeton | Mercer | 37 24 | 81 15 | | | | | Z. Fellers, postmaster | Very light; not noticed at the time. |
| 22 | Romney | Hampshire | 39 17 | 78 44 | | | | | J. Shutz, postmaster | Felt by few and not generally noticed at the time; a man and wife awakened by rattling of pitcher; 6 miles east shock accompanied by rumbling. |
| 23 | St. George | Tucker | 39 08 | 79 44 | | | | | W. M. Cayton, postmaster. | Nothing reliable; a few say a low rumbling; one party says house shook. |
| 24 | Union | Monroe | 37 37 | 80 41 | 1 | | | 8 to 10 | J. H. Crosier | Sitting on ground floor; no noise. |
| 25 | Volcano | Wood | 39 14 | 81 24 | | | | | Wheeling Register, September 2, 1886. | "Reports of falling chimneys and cracking walls." |
| 26 | Webster | Taylor | 39 16 | 80 05 | 1 | | | | T. B. Fordyce, postmaster. | Preceded by rumbling; lady lying down, second story, felt tremor and sinking sensation, and noticed oil in lamp shake considerably. |
| 27 | Wellsburgh | Brooke | 40 15 | 80 40 | 1 | | | 30 | Cincinnati Enquirer, September 1, 1886. | "Very perceptible." |
| | ...do | ...do | 40 15 | 80 40 | | | | | Wheeling Intelligencer, September 1, 1886. | Severely felt. |
| 28 | Weston | Lewis | 39 01 | 80 35 | 2 | | | | N. H. Brown, postmaster. | Duration, a few seconds each; felt perceptibly; suspended objects swung. |
| 29 | West Union | Doddridge | 39 16 | 80 51 | | | | | F. P. Ford, postmaster | Not felt. |

*Report of earthquake observations, earthquake of August 31, 1886*—Continued.

**WEST VIRGINIA—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | m. | s. | | |
| 30 | Wheeling | Ohio | 40 03 | 80 49 | 2 | | | | Wheeling Register, September 1, 1886. | Violent trembling, lasted several seconds; most distinctly felt in second and third stories; scenes of wild confusion in hotels; not felt by one out of four throughout the city; not generally felt on the streets. |
| | do | do | 40 03 | 80 49 | | N. to S. | | | Wheeling Intelligencer, September 1, 1886. | Very severe; direction shown by articles hanging on wall; duration, first shock fourteen seconds; interval about four minutes; second shock noticed only in upper stories, and lasted four or five seconds; during first shock chandeliers swung, crockery rattled, clocks stopped, rocking-chairs rocked, articles thrown from mantel; a meeting stampeded and many frightened from buildings; decidedly undulatory; intense excitement. |
| 31 | White Sulphur Springs | Greenbrier | 37 48 | 80 02 | | | 1 | | Richmond State, September 1, 1886. | Very perceptible; duration, nearly one minute; everybody felt it. |
| 32 | Willow Grove | Jackson | 38 56 | 81 53 | | | | | J. N. Trumble | |
| 33 | Winfield | Putnam | 38 32 | 82 00 | 2 | | | | Cincinnati Enquirer, September 1, 1886. | Interval, fifteen minutes; distinct shocks; buildings rocked and lamps overturned. |

**WISCONSIN.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Augusta | Perry | 44 40 | 91 09 | | | | | S. S. Moore, postmaster | Not felt. |
| 2 | Beloit | Rock | 42 30 | 89 03 | | | | | Chicago Inter Ocean | A slight touch was noticeable. |
| | do | do | 42 30 | 89 03 | | | | | Beloit Daily Free Press, September 1, 1886. | Slightly noticeable; several experienced an uncomfortable, and some a sickening sensation; discernible only on the most solidly-made buildings; Dr. Mellen felt building rock; chandelier swayed; he ran from building. Mr. Orten noticed swaying; not felt on first floor. Mr. and Mrs. Goodwin in room, sitting at opposite sides of table, thought house was turning over; suspended objects swung. "A general shaking up." Lasted two minutes. |
| | do | do | 42 30 | 89 03 | | | | | Chicago Herald, September 2, 1886. | Several felt peculiar sensation, thought to be a mild earthquake; buildings rocked, chandeliers, etc., swung. Particularly felt in Goodwin Hotel and Parker Block. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**WISCONSIN—Continued.**

| No. | Locality | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | m. | s. | | |
| | Beloit | Rock | 42 30 | 89 03 | | | | 3 | O. H. Orton | Very light; moved table I was sitting against. Dr. Meller, in next room, came in at once and asked if I felt it. His chandelier moved and he felt movement. |
| | ......do | ....do | 42 30 | 89 03 | 1 | E. to W | | 10 | W. A. Meller, M. D | Chandelier swung two or three inches from E. to W.; noticed only in this house and Goodwin House, both strong buildings; no noise; duration not over thirty seconds. |
| | ......do | ....do | 42 30 | 89 03 | | | | | H. C. Powers | Did not feel shock; gives experiences of others. |
| 3 | Buncombe | La Fayette | 42 31 | 90 26 | | | | | W. W. Gillette | Not felt. |
| 4 | Chamber's Island Light-station. | Door | 45 12 | 87 22 | | | | | L. S. Williams | Do. |
| 5 | Durand | Pepin | 44 37 | 92 00 | | | | | E. L. Brown | Do. |
| 6 | Eagle Bluff Light house. | Door | 45 10 | 87 20 | | | | | William Duclou, keeper | Do. |
| 7 | Eau Claire | Eau Claire | 44 49 | 91 30 | | | | | M. Causius | Do. |
| 8 | Fond du Lac | Fond du Lac | 43 42 | 88 30 | | | | | (?) postmaster | Do. |
| 8 | Green Bay | Brown | | | | | | | Chicago Inter Ocean, September 2, 1886. | Felt slightly; first observation at Green Bay Signal-station taken to-day. |
| | ......do | ....do | | | 1 | E. to W | | 5 or 6 | C. D. Suydam | Noticed by very few; two parties standing at desk, second story, noticed desk move and chandelier swing E. to W. 3 or 4 inches; one felt floor move. |
| 9 | Janesville | Rock | 42 41 | 89 03 | | | | | Madison (Wis.) Daily Democrat, September 2, 1886. | Large brick building shaken; at Business Men's Association chairs moved, billiard balls rolled, members left building. Felt at Myers House and other parts of city; "excited considerable attention." |
| | ......do | ....do | 42 41 | 89 03 | | | | 5 or 6 | Chicago Inter Ocean, Sept. 1, 1886. | Meeting at Business Men's Association broken up, members thinking building would fall. |
| | ......do | ....do | 42 41 | 89 03 | | | | | H. C. Powers | |
| 10 | Juneau | Dodge | 43 24 | 88 43 | | | | | L. E. Noughton, postmaster. | Not felt. |
| 11 | La Crosse | La Crosse | 43 48 | 91 18 | | | 2 | | Walter Tillman | In third story brick building very light; probably more than one shock; lasted perhaps two minutes. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**WISCONSIN—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | *m.* | *s.* | | |
| | La Crosse | La Crosse | 43 48 | 91 18 | | | 2 | | La Crosse Morning Journal, September 2, 1886. | "Sharply felt." One or two dozen men at a lodge in a third story; one felt dizziness and swimming sensation in head as if his cigar was too strong. On the instant he saw swaying of gas jets and some one cried "building shakes." All noticed it and think it lasted two minntes. Two men writing now recall trembling of tables, as if the legs were uneven, causing them to adjnst tables. No one else felt it. |
| 12 | Madison | Dane | 43 04 | 89 25 | | | | | J. S. Hawks | Not felt. Letter forwarded by H. C. Powers. |
| | do | do | 43 04 | 89 25 | | | | | No name | Letter sent by H. C. Powers. Not felt at Madison or the region northwest. |
| | do | do | 43 04 | 89 25 | | | | | Madison Daily Democrat, September 3, 1886. | A lady top of European Hotel, reading, heard chair move—a sort of vibrating—thought it a dog rubbing the chair; dog was out. |
| 13 | Mauston | Juneau | 43 48 | 90 06 | | | | | T. P. Naughton, postmaster. | Not felt. |
| 14 | Milwaukee | Milwaukee | 43 03 | 87 57 | | | 1 | | Associated Press | Large buildings shook to their foundations; people fled to the streets; windows broken in numerous houses and pictnres shaken down; no particular damage; felt only in larger buildings and central part of city; severest in fashionable residence district; lasted nearly a minnte. |
| | do | do | 43 03 | 87 57 | | | | 15 | Chicago Herald, September 2, 1886. | "An ague-like shock;" people rushed from all tall tenements. |
| | do | do | 43 03 | 87 57 | | | 1 | | Wisconsin State Journal, September 1, 1886. | Large buildings shaken violently; inmates fled to the streets; pictures fell, chairs and tables danced, upper stories of high buildings rudely shaken; not felt in low ones next door. At Hampshire block and Belvidere flats greatest consternation seized the inmates. On the fourth floor, Colby building, a solid table that six men could not move, with twelve clerks at work aronnd it, slowly slid away from clerks and their stools moved toward each other. The floor seesawed with an easy undulating, and the walls swayed in responsive motion; clerks rushed to the ground, feeling floor of corridor shake and tremble as they passed; did not retnrn for a half hour; shock most violent at above-named places; felt in many parts of city; lasted a little over a minute. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**WISCONSIN—Continued.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | m. | s. | | |
| | Milwaukee | Milwaukee | 43 03 | 87 57 | | | | | T. A. Greene | Conditions favorable, but did not feel it; many others felt it; easy undulating; no noise. |
| | do | do | 43 03 | 87 57 | | | | | J. G. Hagen, S. J. | |
| | do | do | 43 03 | 87 57 | | | | | F. D. Duffey | On first floor; floor above creaked for a minute; no shock, no motion; thinks not felt except in high buildings. |
| | do | do | 43 03 | 87 57 | | | | | H. Paul, postmaster | "Very light," noticed only on third or fourth floors; set suspended objects swinging. |
| 15 | Neillsville | Clark | 44 32 | 90 36 | | | | | I. T. Carr, postmaster | Not felt. |
| 16 | Port du Most Light | Dove | 45 23 | 86 56 | | | | | P. Knudsen, keeper | Do. |
| 17 | Prairie du Chien | Crawford | 43 03 | 91 11 | | | | 10 | Rev. J. G. Hagen, S. J. | On first floor frame building, just noticed; on second, much stronger, swaying oil in lamp; on third, professors left rooms; not observed in new brick building nor on N. side frame buildings; several shocks felt, direction from the SE. |
| 18 | Racine | Racine | 42 44 | 87 50 | | | | | C. J. Jackson | Not felt. |
| 19 | Sauk City | Sauk | 43 16 | 89 47 | | | | | H. C. Powers, Beloit | Not felt. "Not felt in middle of State." |
| 20 | Sheboygan | Sheboygan | 43 44 | 87 43 | | | | | Carl Zieliro, postmaster. | Not felt. |
| 21 | Sherwood Point Light-station. | | | | | | | | H. Stanley, keeper | Do. |
| 22 | Sturgeon Point Light-house. | | | | | | | | L. Cardy, keeper | Do. |
| 23 | Twin River Point Light-station. | | 44 10 | 87 30 | | | | | A. J. Davenport, keeper. | Do. |
| 24 | Waukesha | Waukesha | 43 00 | 88 16 | | | | | H. C. Powers, Beloit | |
| 25 | Wausau | Marathon | 44 58 | 89 36 | | | | | A. C. Clark | Not felt; very careful inquiries made. |

**CUBA.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. m. | Duration. s. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Cardenas | | 23 02 | 81 10 | | | | | J. M. Churchill | Not felt in town or vicinity. |
| 2 | Havana | | 23 09 | 82 20 | | | | | A. W. Reyes, M. D. | Lamps moved; there was an oscillation in La Isabella; information from others. |
| | do | | 23 09 | 82 20 | | | | | Benito Viñes | Not felt. |
| 3 | Sagua la Grande | | 22 51 | 80 06 | 2 | | | | A. W. Reyes, M. D. | First shock lasted three or four seconds; second, eight or ten; interval, eight or ten seconds; Sagua seventeen kilos from La Isabella. |

*Report of earthquake observations, earthquake of August* 31, 1886—Continued.

**THE ATLANTIC OCEAN.**

| No. | Locality. | County. | Latitude. | Longitude. | No. of shocks. | Direction. | Duration. | | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ | ° ′ | | | m. | s. | | |
| 1 | Off Bermuda, etc | | | | | | | | New York World, September 6, 1886. | Officers steamer *Trinidad* felt nothing while at Bermuda or on the voyage to New York City. |
| 2 | Off Cape Hatteras | | | | | | | | do | Captain Lotrop, of the *Agenor* met a heavy sea from the SW., a brisk NE. breeze blowing at the time; no shock felt. |
| 3 | Thirty-five miles east of Hatteras. | | | | | | | | New York World, September 7, 1886. | Captain Filton, of the *Sam H. Crawford*, Baltimore to Savannah, when 35 miles off Cape Hatteras, heard sound as of heavy thunder under vessel. |
| 4 | Off Cape Romain (37 miles northeast of Charleston Light. | | | | | | | | New York Herald, September 7. | Captain Allen, *Nina Mathilde*, port of Spain (Trinidad) to New York, when 12 miles southeast Cape Romain Light, was thrown from bed by a severe shock and thought vessel was on a reef; got east of land, in 12 fathoms, five minutes later, and felt second shock, and after twelve minutes a third, both lighter than the first. |
| 5 | Charleston (50 miles off the harbor). | | | | | | | | New York Sun, September 27, 1886. | Leo Voegel, captain *City of Palatka*, Charleston to Florida, when 8 miles off shore. felt earthquake shock; lasted about half a minute, accompanied by a rumbling; during sensation there was a calm sea before, and after a heavy sea. |
| 6 | Off Delaware Bay | | | | | | | | W. W. Smith, keeper | On Five-fathom Bank Light vessel No. 40 no shock felt. |
| 7 | Thirty miles south of Halifax. | | | | | | | | Captain Jacobs | Captain Jacobs, schooner *Mollie Adams*, a heavy gale, lasting seven hours; split jib and foresail and washed 50 barrels mackerel overboard. |
| 8 | Hampton Roads | | | | | | | | Captain Tretwurst | At cabin table writing; felt vessel heave slightly, and she appeared to scrape lightly on bottom; has felt many slight shocks, and is confident it was an earthquake. |
| 9 | Winter Quarter Light-vessel No. 37 (off Virginia and Maryland line). | | | | | | | | A. Jackson, keeper | Not felt. |
| | | | N. 34 16 | W. 75 08 | | | | | | British steamship *Willesden* felt earthquake evening of August 31; sea suddenly became greatly agitated; ship trembled perceptibly. |

# THE GEOLOGY OF CAPE ANN, MASSACHUSETTS,

BY

NATHANIEL SOUTHGATE SHALER.

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# LETTER OF TRANSMITTAL.

UNITED STATES GEOLOGICAL SURVEY,
ATLANTIC COAST DIVISION,
*Cambridge, Mass., June* 20, 1888.

SIR: I herewith transmit to you the manuscript of a report on the surface and under Geology of the Island of Cape Ann and the neighboring parts of the Massachusetts shore. Although I have long had this work in contemplation and accomplished a small part of the task more than twenty years ago, by far the larger part of the field observations embodied in this memoir have been made by my assistant, Mr. Ralph S. Tarr. All the detailed observations on the dikes and joint planes and on the petrography of the district are his. In these parts of the work I have supplied only the general project and certain details concerning the method of presentation. In the petrographic work we have had the assistance of Dr. J. E. Wolff, assistant geologist of the Survey.

I am indebted to Messrs. George Bridge Leighton and John L. Gardner, jr., for their services in obtaining photographs from which all the illustrations of this report have been prepared.

Very respectfully, your obedient servant,

N. S. SHALER,
*Geologist in Charge.*

HON. J. W. POWELL,
*Director U. S. Geological Survey, Washington, D. C.*

# THE GEOLOGY OF CAPE ANN, MASSACHUSETTS.

By N. S. Shaler.

## NATURE AND OBJECTS OF THIS REPORT.

The island of Cape Ann and the neighboring portion of the mainland of Massachusetts form a remarkable salient at the northern extremity of Massachusetts Bay. The topographic individuality of this area and its general relations to the shore line of New England make it an attractive field for inquiry. Although it is proposed in the end to assemble in a general report the information gained in the study of the Atlantic coast line, it seems desirable from time to time to set forth the more important of these results in the form of detached memoirs. It will be a number of years before it will be possible to prepare a final report, and in the mean time by separate publications, the more important results obtained during the progress of the inquiry can be placed in the hands of other students of this interesting geological field.

I propose to set forth in the following pages what has been ascertained concerning the following points: First, the general structure of the district in question, and next, the superficial geology of this field under the following heads, viz: the distribution of the glacial drift, the amount of erosion during the last ice period, and the action of the sea upon the shores; afterwards I shall take up the structure and nature of the bed rocks, the variation in the character of the hornblendic granitites which compose the region, the various dike stones which intersect it, the character, origin and effect of the joint planes and the quarry rifts of the rocks, and, lastly, the relations of the region to the anticlinal axis of which it forms a part.

The field included in this inquiry at first sight appears to present little of geological interest; it has received hardly any attention from the geologists who have worked in eastern Massachusetts. This neglect is due to the fact that the geologic structure of the region is relatively simple. As will be seen from the geological map accompanying this report, the bed rocks are composed altogether of granitites and associated intrusions of an igneous nature. The absence of distinctly stratified deposits gives a uniform aspect to its structure and appears at first sight to afford little promise of important results to geological inquiry. Despite the disadvantage arising from

the lack of variety, this region affords certain peculiar advantages to the student for the prosecution of various inquiries. The general deforested condition of the island of Cape Ann, a feature which is shared in part by the mainland division of the area included in this report, enables the observer to note certain peculiarities in the distribution of the drift which are often obscured by forests in other parts of this region. The extensive shore line and the thoroughness with which the rocks near it have been stripped of their original covering by the action of the sea make it possible to observe the details of structure of the rocks along a section which has a length of more than thirty miles. (See Pls. XXXII–XXXV.) As will be seen hereafter in the body of this report, we are able from a study of this section to determine in a satisfactory manner many points concerning the structure of the rocks. The extensive quarries which exist also favor the prosecution of several inquiries.

These favoring features made it seem desirable to undertake on this ground a careful study as to the distribution of dikes in a mass of crystalline rocks, which, as we shall see hereafter, originally constituted the foundations of a great anticline. The field also seemed advantageous for a careful study of joint phenomena in their relation to the dikes, and to the strains which we may assume to have been developed in the formation of the anticlinal ridge. In this connection it also seemed well to undertake some inquiry into the nature of the rift or natural splitting planes which are availed of by the quarrymen in the separation of blocks of the granite from their bed. I am not aware that any of these inquiries have ever been prosecuted in the manner in which they are considered in this report. Lastly, the peculiar composition of this shore in relation to the sea makes it possible to study the effect of ocean waves of great magnitude on rocks which, though generally hard, vary much in the resistance which they offer to the impact of the waves. No other point on our coast line affords such opportunities for this inquiry as Cape Ann. The considerable extent to which this promontory projects into the open sea and the absence of reefs or other barriers between it and the wide ocean, together with the deep water which extends seaward from the shore, expose it to more powerful surges than assail most other parts of our rock-bound coast. As will be seen in the section of this report which deals with the problem of marine action since the close of the glacial period, we learn much from studying here the action of the sea.

The promontory of Cape Ann projects about twelve miles from the general line of the shore. It is composed of two sections, an outer part, made up of the main island which receives the name of the cape, and a few small islets all having a core of bed rock more or less enveloped with detrital materials, and an inner section which, though much cut up by deep indentations of the sea, is not completely sepa-

CLIFFS NEAR LOBLOLLY COVE, SHOWING POST-GLACIAL MARINE EROSION, FORMING DISTINCT BENCH ALONG THE SHORE.

rated from the mainland. The outer portion of the promontory, to which we give the name of the Island of Cape Ann, was at the close of the glacial period and for some time thereafter completely separated from the mainland by the tolerably deep inlet which bears the name of Squam River. The considerable amounts of detrital matter borne in by the sea which have accumulated in the Gloucester harbor have in recent times closed the southern extremity of this fiord by a beach wall. Behind this wall the usual growth of marine marshes still further effected the closure, so that when the country was settled by Europeans there was an isthmus of marsh and beach having a width of about one-third of a mile which separated the waters of Gloucester harbor from those of Squam River. This barrier has been artificially cut through so as to permit the passage of boats, and thus the original insulated character of the cape has been restored.

The fact has been stated that the whole of this salient is much exposed to the action of the ocean surges. An inspection of the soundings given on Coast Survey Chart No. 109 shows that they rapidly and somewhat uniformly descend from the shore line towards deep water. The ten-fathom line is generally found at a distance not exceeding a mile from the shore, and at several places, particularly near Eastern Point and near the northern promontories of the island, it comes to within less than half a mile of the shore. The contouring line drawn on the soundings of twenty fathoms is at no point more than two and a half miles from the shore of the main island and generally is not much more than one and a half miles from its margin. Beyond the twenty-fathom line the bottom descends steadily to the depth of from twenty-five to fifty fathoms, these depths being generally attained at distances of not more than four miles from the coast. A comparison of the position of our shore with reference to deep water will make it plain that these features of the bottom favor the action of ocean waves on this part of the coast, and therefore fit the shore to be the seat of special inquiry on this point.

## GENERAL GEOGRAPHIC AND GEOLOGIC RELATIONS OF THE CAPE ANN DISTRICT.

The island of Cape Ann is composed altogether of three classes of rocks—an original field of the nature formerly known as syenites, rocks now designated by petrographers under the name of hornblendic granitites, which occasionally approach a true granitic character. These granitites, as we shall afterwards show, probably represent a succession of dislocatory movements partially due to true injections and in part to faulting, the variations in the character of the crystalline matter being due in the main to these displacements.

Through these granitic bed rocks, which compose about nine-tenths

of the foundations of the district, extend very numerous dikes. As will be seen on the map, considerable portions of the shore line are so far penetrated by these intrusions that more than one-tenth of the surface is occupied by them. Unfortunately for the completion of the observations, the internal area of Cape Ann as well as of the neighboring mainland is pretty deeply and evenly covered by glacial drift, more than three-fourths of those areas being hidden from view. All the evidence, however, goes to show that the proportion of dike stones to the common granites is quite as extensive in the interior and drift-covered areas as it is along the extended shore line.

On top of the bed rocks we have, as before remarked, an extended sheet of drift deposits distributed with greater uniformity than along any other portion of our shore known to me. As will be seen hereafter when we come to set forth the results of special study on this drift deposit, it consists mainly of frontal moraine or material which has been shoved forward at the front of the ice sheet.

In none of its geological features, neither in its bed rocks nor in the injected materials nor in the drift, does the region of Cape Ann have an individual character. The granitites which appear and which constitute the greater part of the region are essentially like those occurring all about the borders of Massachusetts Bay. With slight exceptions the dike stones are paralleled by others found in various parts of eastern Massachusetts. The morainal accumulations are but fragments of a large field in which these deposits occur. The peculiar advantage of this district, that which has led me to make it the subject of a memoir, is found in the fact that several geologic features exhibited there are better placed for inquiry than elsewhere. It will be evident from an inspection of the maps that the Cape Ann promontory is formed by the northeastern projection of a ridge of crystalline rocks, generally syenitic, extending from near Dedham, Mass., in a northeasterly direction, until cut off by the sea. To the northwest and to the southeast of this extended axis we have rocks of a less crystalline nature verging upward into distinctly sedimentary deposits. On the south side of Boston Bay, extending from Nantasket in a southwesterly direction, we have a similar axis; the two are obscurely united at their southwestern extremity in the highlands and peaks of the Blue Hills, which attain a considerable altitude.

The general structure of these ridges makes it clear that they are in their nature anticlines, and that the Blue Hills district is situated at the southeastern extremity of the trough which is inclosed between them, thus forming what we may term the node of the anticline. Between these two anticlines, within which lies Boston Bay, we have a much disturbed syncline, the only portion of which open to investigation lies in and about the city of Boston. The greater


ERODED DIKE CHASM NEAR WHALE COVE, 20 FEET ABOVE PRESENT SEA-LEVEL.


VIEW NEAR CAPE HEDGE, MASSACHUSETTS, SHOWING SCOURING ACTION OF SEA ON LITTLE-JOINTED ROCK OF VARYING HARDNESS.

portion of this syncline has been entirely cut away by erosive action, by the work of rivers, by the action of the sea, and in larger measure by the erosive power of glacial ice. So profound has been this erosion, that it has not only destroyed the greater part of the sedimentary deposits down to the water-level, but it has also removed a considerable portion of the plutonic rocks which were thrust up beneath the old anticlines, at the same time stripping off all the newer-bedded rocks which originally lay upon their surface.

It is also evident that profound faulting attended the formation of this syncline, accompanied by a considerable development of minor folds within the field occupied by the syncline itself. Through these faults extensive extrusions of igneous rock took place, in part in the form of dikes and in part in the form of more superficial flows, the remains of which are still found in a profoundly eroded condition in the porphyries and felsites of Lynn and in the similar rocks and accompanying ash-beds of Cohasset. From what is left of the old syncline we may fairly arrive at the conclusion that only the southeastern extremity of this trough has been preserved to the present day. By far the greater part of its area has been deeply eroded and is hidden beneath the surface of the sea, in part covered over by recent accumulations of sediment. We shall consider the history of this erosion when we come to treat of the recent abrasion which has taken place on the surface of Cape Ann.

## GENERAL FORM OF CAPE ANN ANTICLINE.

Turning now to the general form of the Cape Ann anticline, as we shall hereafter term it, we find that it consists of a somewhat irregular ridge having an average width of about ten miles. On the north this ridge is bordered by lowland worn in the softer rocks which lie upon its north side, and occupied in the main by the drainage of the Charles, the Mystic, the Saugus, and the Ipswich Rivers. The delimitation of the ridge on the north is by no means distinct; it is, however, sufficiently clear to give a certain accent to it on that side. On the south side it is bordered by the waters of Boston Bay.

The surface of this anticline, though originally united, is now much divided by a number of tolerably deep valleys, some of which attain to the level of the sea. The southernmost of these, that of Charles River, attains very nearly to the sea level, the highest point of the ridge where it is crossed by the stream being not more than fifty feet above tide mark. The Mystic also forms a deep excavation through the anticline; the Saugus River, though its headwaters do not extend beyond the limits of the ridge, deeply divides it. From Manchester to Essex another depression appears in the axis which attains almost to the level of high tide, and the fiord which separates Cape Ann from the mainland extends, save for the postglacial dé-

bris which has accumulated in it, to a considerable depth below the water line. These several troughs owe their existence to pre-glacial streams and in larger share to the work of the ice during the last glacial periods. Besides these conspicuous meridional valleys we find many others having the same general trend and probably to be explained in the same manner, through the action of glacial ice operating on rocks which were mechanically weak.

Besides the above-mentioned valleys this region exhibits another series of depressions, less conspicuous because they are not to the same extent occupied by water, but on the whole equally noteworthy. These valleys extend in the direction of the anticline itself, having a general trend of about N. 10° to 20° E., S. 10° to 20° W. (See Pls. XXXVI, XXXVII.) Although tolerably evident in every part of this ridge, these valleys are most conspicuous in the region in and about Cape Ann. On this island they give more expression to the surface than any other elements of its topography. With the map of the island before him the reader will perceive that the Cape is in good part divided into two regions by the deep indentation of Gloucester harbor and a corresponding indent known as Sandy Bay. Between these two depressions, each of which has a length of several miles, the surface of the Cape is, save for the encumbering envelope of drift, much lower than along the other part of its area. If it were depressed fifty feet below its present level, although but a small part of its surface would be submerged, a nearly complete channel would be formed extending from Rockport to Gloucester, and Eastern Point would be cut off from the main island. Besides this most considerable northeast and southwest valley, there are several others approximately parallel to it on different parts of the island and on the neighboring mainland. One of these extends from the indentation just west of Halibut Point, known as Folly Cove, for a distance of more than two miles into the body of the island. It is possibly protracted across the intervening space to Squam River near Riverdale, though in its central portions it is almost completely effaced by the thick deposits of morainal matter.

The last-named group of valleys has an origin which is not as simple as those which extend in a northwest and southeast direction. In part they are due to glacial erosion on portions of the strata which are mechanically weak. As will be seen by the map, certain belts of dikes containing the most numerous and characteristic of these intrusions have the same course as these valleys. It is likely that the resistance of the rocks to glacial erosion was considerably diminished along the lines which they occupy, and that in part the development of valleys is due to this cause; in part also they may be attributed to a totally different origin. The direction of the morainal fronts corresponds approximately to that of these valleys. The morainal matter is arranged in successive ridges roughly par-

VIEW NEAR CAPE HEDGE, SHOWING SCOURING ACTION OF SEA ON LITTLE-JOINTED ROCK OF UNIFORM HARDNESS.

VALLEY BETWEEN BRIAR NECK AND MAIN-LAND, LOOKING NORTHEAST—THATCHER'S ISLAND LIGHT-HOUSES IN DISTANCE—SHOWING ONE OF THE NORTHEAST AND SOUTHWEST VALLEYS OF CAPE ANN.

allel, the intervening valleys having often the same general character as the troughs produced by the erosion of the bed rock.

Besides the northwest and southeast valleys which are evident in the topography of the country, it is clear that there is at least one other beneath the level of the sea lying in the space between the Salvages and the eastern shore of Cape Ann. Yet another more obscurely indicated lies between Straitsmouth Island and Gap Head, being continued southwardly between Thatcher's Island and Milk Island. Judging from the soundings, it appears likely that there are other north and south troughs partially effaced by sediments on the sea floor farther out from the shore. One such appears about three miles east of Straitsmouth Island and yet others farther out to sea. The insufficiency of the soundings, which, though numerous enough to serve the needs of the navigator, do not meet those of the geologist, makes it impossible to determine with accuracy the form of these interesting troughs.

The soundings also indicate, though obscurely, the extension of the Cape Ann ridge for ten miles or more eastward of its present limit. The ridge which appears to represent the submarine continuation of the Cape is much lower and more rounded than the portion of the anticline which lies above the water level, but the distance between the soundings is so great that a basis for precise conclusions can not be secured.

The height of the anticlinal ridge which includes the district of Cape Ann is remarkably uniform. The most elevated part of it does not lie within the field we are considering, but is found at Bear Hill, in the township of Stoneham, where it is about four hundred feet above the level of the sea. Within the limits of Cape Ann the highest point is about two hundred feet above the sea level. The depths of fiord-like indentations which extend in a northwest and southeast direction is not accurately determined, but probably at no point does it exceed one hundred feet below the ocean level. At first I was disposed to consider this uniformity in height as due to the likeness of glacial action on different parts of the surface. Further inquiry has convinced me that it is to be explained by the operation of the sea in the former geologic periods, when it was at a somewhat higher level than at present. All along our coast we have more or less clear indications of a great planing agent, which has cut off the summits of the mountains back a distance of scores of miles from the present shore line, reducing the surface to something like a general level, leaving a few isolated peaks here and there upon the bench. The level of this bench varies on different parts of the shore. In Massachusetts it ranges from the present level up to the height of about four hundred feet. In Virginia this marine bench is more distinct than in New England, for the reason that its aspect has been less affected by glacial action.

Owing to the action of the sea in former times at higher levels, the mountains of the coast belt, though having as much geological relief as those of the interior region, have been deprived of their topographic value and are planed down to the very roots.

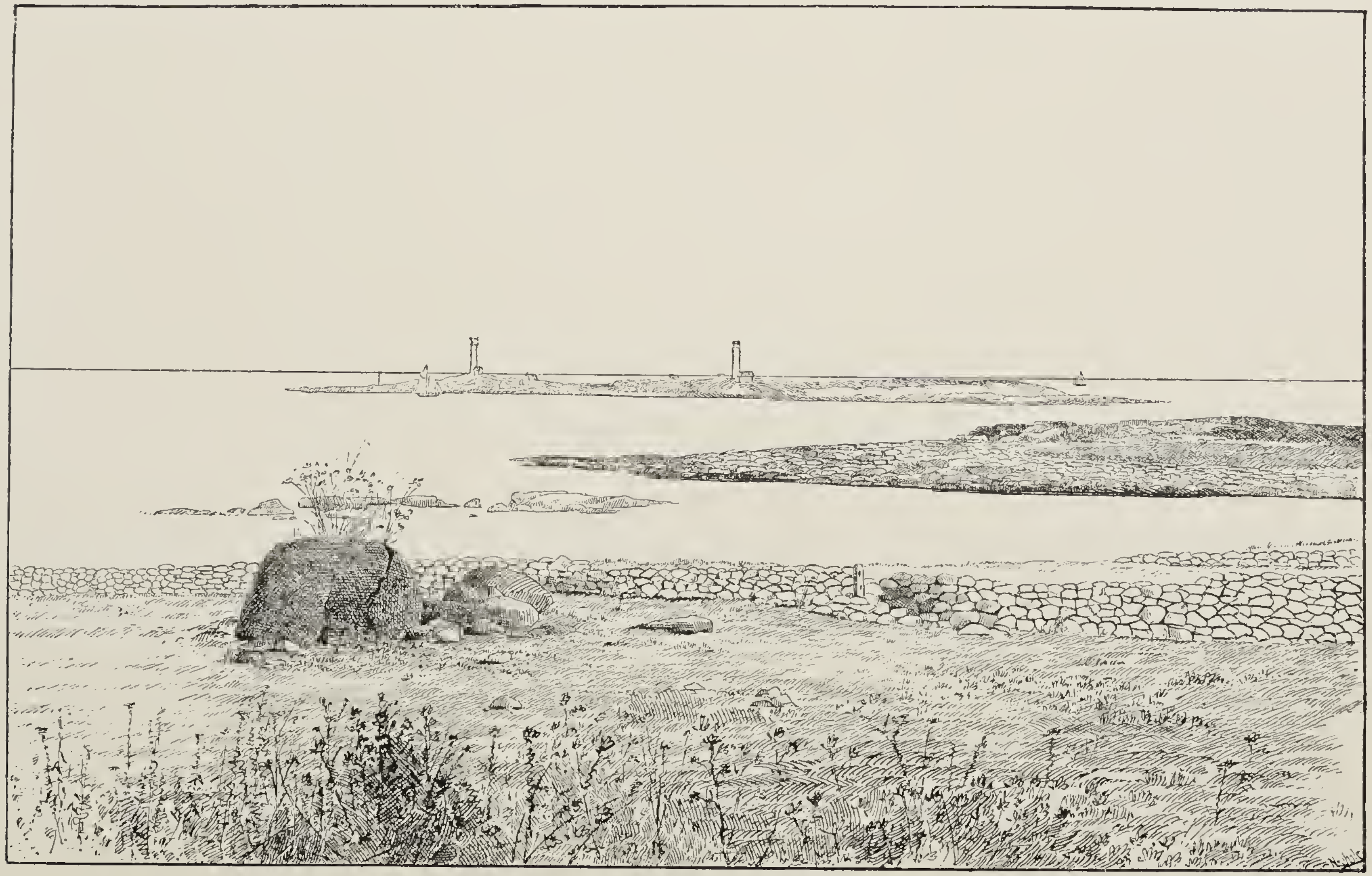
## NATURE AND DISTRIBUTION OF DRIFT DEPOSITS.

The drift deposits of this region, though in general character much like those found in the neighboring districts, presents some interesting peculiarities. The whole of the central field of the island of Cape Ann and the neighboring portions of the mainland included in this report is covered with a coating of frontal moraine somewhat irregularly distributed but generally attaining a considerable depth. Here, as generally elsewhere, the accumulations consist of three elements: shoved material, or that which has been urged forward in the advance of the ice sheet as the soil is carried onward in front of a scraper. (See Plates XXXVIII, XXXIX, XL, XLI.) Around this shoved matter, or that which owed its transportation to the advancing ice front, we find accumulation of finer material arranged in the form of kames. (See Pl. XLII.) Yet farther from the former face of the ice lie sheets of sand arranged so as to afford a tolerably horizontal surface to which I have given the name of "frontal aprons." On top of the shoved moraine, and for some distance back of its line, we find deposits which have received the name of "ground moraine," composed of materials originally contained in the body of the ice which at the time of its melting dropped upon the surface.[1]

### SHOVED MORAINES.

The frontal or shoved moraine material within the limits of the island of Cape Ann is remarkably thick, having on the average a depth exceeding fifty feet, and at some points possibly exceeding one hundred and fifty feet. (See Pl. XLIII.) It is arranged in the form of rudely parallel ridges, which extend from N. 25° to 40° E. and S. 25° to 40° W. These ridges are very broad and the valleys between them by no means distinct. In most cases they appear to be thickest on the summits of the low elevations of granitite, which are separated from each other by the valleys which we have already described. The surface of these morainal ridges is very irregular, being cast in the mammelate form so common in such accumulation. (See Pl. XLI.) The most remarkable feature observable in this morainal matter is the extreme abundance of large erratics which it contains. (See Figs. 44, 45.) These great bowlders are so abundant that over most of the surface occupied by the shoved moraine they make all tillage impossible. Indeed, on a large part of the area it is

[1]Geology of Martha's Vineyard, N. S. Shaler, Seventh Ann. Rept. U. S. Geol. Survey, 1886-'87, p. 314.



SHORE AT EMERSON'S POINT, WITH THATCHER'S ISLAND IN DISTANCE; LOOKING EAST.

SERPENT KAME DESCENDING NORTH SLOPE OF SOUTHERN FRONTAL MORAINE NEAR ROCKPORT ; LOOKING SOUTH.

difficult to find a place to set the foot between the closely packed erratics. In the most of the morainal matter the proportion of bowlders exceeding one foot in diameter amounts to not less than one-half the total mass. At certain points the percentage of the large erratics is so increased that there is no fine material to fill their interspaces; the result is that the heap remains open, presenting cavities which extend in many cases to the depth of twenty feet or more below the surface, the whole mass appearing in the landscape like the ruins of Cyclopean masonry. (See Pl. XXXIX.)

Wherever the seeds of trees could have found soil enough to afford them root vegetable waste has filled the hollows between the stones and masked the position of many parts of this open-textured moraine. Nevertheless a considerable part of the accumulation, which I have estimated amount to one-fiftieth of the whole, remains completely without vegetable coating except for the lichens which have found place upon the erratics.

### FORM OF DRIFT DEPOSITS.

Returning to our consideration of the general form exhibited by these deposits, we note that the southern part of each division of the shoved moraine appears to be steeper and more stony than the northern part. (See Pls. XL, XLI.) This is probably due to the overriding of the moraine in the frequent slight advances of the glacier, and in part to the washing of the sediments from the ice front upon the slope of the moraine as it was abandoned in the process of glacial retreat.

On the northern exposed face of the moraine, the boundary between that accumulation and the surface of the bed rocks is tolerably sharp. The partition between the two areas is generally indicated by a depression, in which lies a series of swamps. This depression is on an average ten to twenty feet in depth and has a width of several hundred feet. North of this trough there are occasional patches of what appears to be shoved moraine material; but the greater portion of the incomplete sheet of detritus apparently has the nature of ground moraine or that which was formed when the melting ice dropped its débris on the surface. At no point have I observed this accumulation having a thickness of more than five or ten feet, and the materials generally occupy less than half of the bed-rock surface.

Although the shoved moraine occupies about three-fourths of the area of the island of Cape Ann, the district contains representatives of the other structures which were formed on the front of the ice. The kame deposits are rare; they are mainly found either upon the southern portion of the island of Cape Ann and the neighboring mainland or on a narrow strip along the northern coast. The origin of these kame deposits can readily be explained, provided we accept

the hypothesis concerning their origin which I have elsewhere presented.[1] This hypothesis is, in brief, as follows: From beneath the ice mass there came forth many streams of flowing water, bearing with them great quantities of detrital matter. At the time when these streams flowed the base of the ice was considerably beneath the present level of the sea. On the floor of that sea, immediately in front of the glacier, the whirling currents, originated in the ocean waters by the swift-flowing glacial streams, formed the peculiarly distributed mounds and valleys of stratified débris which we note as kames. These subglacial streams were rare on the part of Cape Ann which is now above the ocean level, for the reason that they were drawn away into the deep valleys which lie east and west of its elevated mass. We know by the facts exhibited elsewhere that subglacial streams, though occasionally appearing along all parts of the ice front, are most likely to find their channels in the depressions of the surface which lie beneath that front. Thus the kame deposits were probably accumulated on territory which now lies beneath the surface of the sea.

In front of the kames normally comes the moranial apron which is so well developed in southern New England. This apron is scantily exhibited for the same reason that led to the paucity of the kame deposits. The materials which compose it were borne to their position by the waters from beneath the ice, and therefore where the kames are poor the apron will be imperfect.

Traces of this frontal apron exist along the southern shore of Cape Ann, especially near Gloucester and in the part of the island which lies east of that town. The traces are so imperfect that they would escape the attention of the geologist who encountered such structures for the first time in this field. The topography of the sea bottom south and east of Cape Ann indicates a general slope reaching outward for some distance from the shore. I have no doubt that the frontal apron determines the uniformity of this slope, as it manifestly does that of the sea bottom south of Nantucket and Martha's Vineyard, where a wonderfully developed frontal apron may be seen to pass below the plane of the sea.

As before remarked, the north shore of the island exhibits some deposits of kame materials and perhaps some faint indications of frontal moraine. It is probable that these structures represent the work of the ice when in its northward retreat it paused for a moment on the portion of the surface which lies below the level of the sea beyond the shores of Cape Ann and there constructed a frontal moraine with its corresponding kame and apron deposits.

As a whole the kame deposits of Cape Ann form an imperfect fringe, extending from Andrews Point westward as far as Annis-

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[1] Geology of Martha's Vineyard, Seventh Ann. Rep. U. S. Geol. Survey.

CREST OF NORTHERN FRONTAL MORAINE, LOOKING NORTHWEST; DOGTOWN COMMONS.

VIEW IN THE ROCKY MORAINE ON THE TOP OF GREAT HILL NEAR ROCKPORT MASSACHUSETTS ON WEST SIDE OF GLOUCESTER AND ROCKPORT TURNPIKE; LOOKING WEST.

quam up to the part of the island which lies next to that inlet and thence to Eastern Point. Faint traces of such accumulations lie on Eastern Point and back of Long Beach. Deposits of this nature are, however, distinctly more abundant on the western versant of the island than on the eastern.

Generally the stratified elements of glacial accmulations do not rise more than sixty feet above the sea level. They are hardly traceable in any continuity above the level of 40 feet; but at a few points they extend in an obscure form nearly to the summit of the great moraines. On Dogtown Commons several of these areas of kame deposits were during the period in which this district was inhabited brought into the state of tilled fields, and now appear as samll pasture lands destitute of bowlders. In part this destitution is due to the fact that the occasional bowlders obstructing the plow were removed. These high-lying benches of stratified drift material probably indicate points where small subglacial streams emerged during the process of the retreat of the ice, bringing forth a quantity of detrital matter and depositing it upon the surface of the shoved moraine at a time when the mass lay below the level of the sea. (See Pl. XLV.)

## SERPENT KAMES.

Usually included among kames are those peculiar forms of the drift deposits often known in New England as Indian ridges, and to which I have provisionally given the name of "serpent kames," for the reason that they are usually serpentiform in their general shape, singularly recalling the artificial snake mounds of the West. Like the kames, they are composed of more or less stratified materials, and in certain cases they appear in positions which clearly indicate that in some way they are related in origin to the ordinary kettle kames.[1]

There is but one distinct serpent kame known to me in the field that we are considering. It lies on the eastern portion of the island of Cape Ann, near Rockport, on either side of the valley traversed by the railway and about twelve hundred feet southwest of the terminus of that road. Its position is shown on the map. (See Plates XXXVII, XXXVIII).

In many respects this serpent kame is the most interesting in this country. Its total length is not far from one thousand feet, but a portion of it lies on either side of the steep valley where it is found. The general position of the mass is indicated in the accompanying plate.

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[1] It is likely that the Scandinavian "escar" is akin to our serpent kames, but as some deposits which have received that name are probably in their nature drumlins, that is to say, masses of till which have been shaped beneath the ice by the process of its movement, it seems to me best for the present at least to abandon the use of that term.

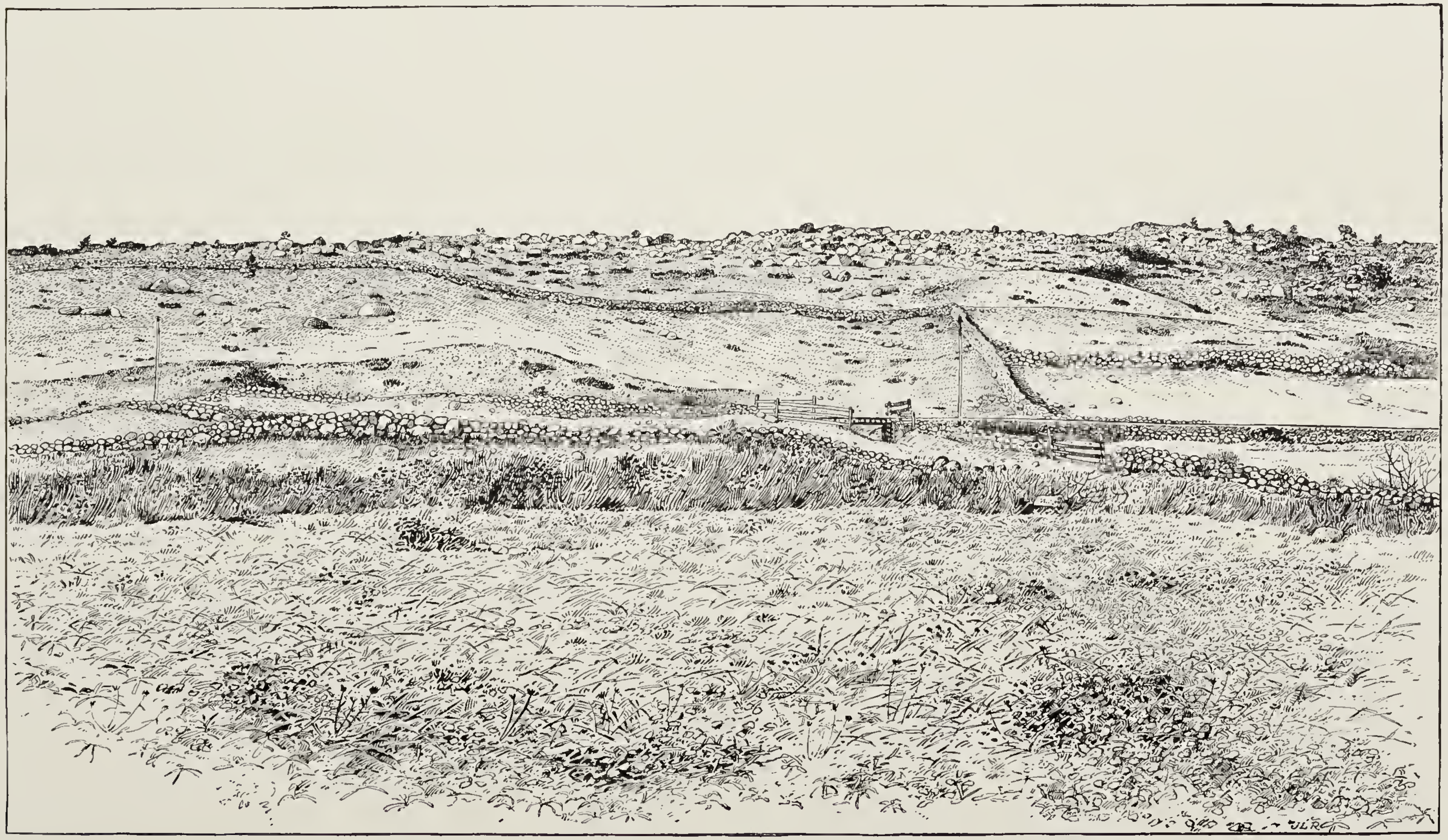
The central portion of the deposit has been in part cut away by the action of the small stream which traverses the valley; in part it probably owes its destruction to the former action of the sea at this level. This is the more likely from the fact that distinct though weakly developed terraces occupy a portion of the valley at a height where the serpent kame is destroyed.

I am disposed to hold, with other glacialists who have considered this problem, that the serpent kames have been formed in the following manner: The outflowing glacial stream excavated channels within the ice which they kept free as long as the currents were strong enough to scour their channels. In the closing stages of the ice sheet, while the front was no longer advancing or perhaps inclined to retreat, these arches were filled in by material borne by the diminished currents. This moraine gives us a better view of the condition of these channels than we obtain elsewhere. We perceive that they are closely molded to the surface, and also that they could be imposed upon considerable thickness of ordinary morainal drift.

### DRUMLINS.

Besides the ordinary frontal deposits above noted, we have in this district a solitary representative of another class of glacial deposits, viz, that of drumlins. This single drumlin lies near Rockport and is known as Pigeon Hill. (See Pl. XLVI.) It is a remarkably good example of its class, and appears in very striking contrast to the surrounding topography. Rising to the height of about two hundred feet above the level of the sea, it has a very symmetrical lenticular form, departing from that outline only on its southern side, where there is a peculiar benching. Unlike the shoved frontal moraine, which lies about it, this ridge is composed, as is usual, entirely of these structures of very compact till in which the proportion of clay is large and the mass extremely compact. Its surface was originally covered by the coating of ordinary ground moraine, containing many bowlders, which have been removed in order to fit it for tillage.

The origin of these peculiar masses of compact till occurring in the form of drumlins is still a matter of debate among geologists. I venture to suggest the hypothesis that they are to be accounted for in the following manner: During the first stage of the Glacial Period the ice sheet had a very much greater extension than during the second portion of the Glacial Period. When at the close of the first stage the ice retreated, it left upon the surface irregular but in places extremely thick deposits of till. During the interval between the first and second stages of the period the southern part of New England remained for a long time free from ice. During this time the till deposit left upon the surface was much eroded, perhaps by the action of the sea, in part doubtless by river action. When the second advance of the ice came to repossess the



SERPENT KAME DESCENDING SOUTH SLOPE OF NORTHERN MORAINE NEAR ROCKPORT; LOOKING NORTH.

ELEVATED KAME PLAIN IN MIDST OF FRONTAL MORAINE, DOGTOWN COMMONS ONE MILE NORTH OF GLOUCESTER; LOOKING SOUTH.

surface, it wore away a large part of the till formed during the first period, leaving the remains of it carved in the characteristic form of our drumlins. It is obvious that these drumlins or lenticular hills have, as the latter name indicates, precisely the form which is given by the action of the ice to any resisting materials of uniform hardness over which it moves. Thus in the Adirondacks, and elsewhere where rocks of uniform hardness exist over considerable fields, we find that glacial action shapes their forms so that at a little distance they are readily mistaken for drumlins.

If this view be correct, Pigeon Hill is a solitary remnant of the original till of the first stage of the Glacial Period, the remainder of that deposit having been worn away by the later action of the ice or entirely covered beneath the thick deposits of shoved moraine.

The outline of the shoved and ground moraine in other parts of the island leads me to suspect that there are several other remnants of this ancient till so far buried beneath the subsequent deposits that their existence can only be conjectured.

A little observation will show the student that nearly the whole of the true frontal moraines in this district have a somewhat drumloid aspect. Each of the moraines is composed of closely crowded hills, the bases of which are conjoined. Looking at these elevations from the east and west, we perceive that they have the general shape of lenticular hills; the curves are not as finished as those of Pigeon Hill or other normal deposits of this nature, but they are of the same general form. In many cases if the encumbering masses of great bowlders were removed the likeness to drumlins would be even clearer than it is at present.

The rounded aspect of these projections of the central moraine is probably to be explained in essentially the same way as that by which we have endeavored to account for the drumlin proper. As is well-known, the front of the glacier is always instable in its position, and a peculiar measure of instability appears to characterize this marginal part of the glaciers belonging to the continental type. We may therefore assume that the cliff-like front of the ice again and again advanced and receded in its position, and at each forward movement there must have been a certain erosion of the deposits which were accumulated during the preceding advances. Although this feature is not very recognizable in the case of this moraine, it is remarkably evident in the Martha's Vineyard moraine, where the overlying of the drift deposits in successive advances is extremely conspicuous.[1]

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[1] Geology of Martha's Vineyard, Seventh Ann. Rept. U. S. Geol. Survey.

## COMPOSITION AND NATURE OF GLACIAL MATERIALS.

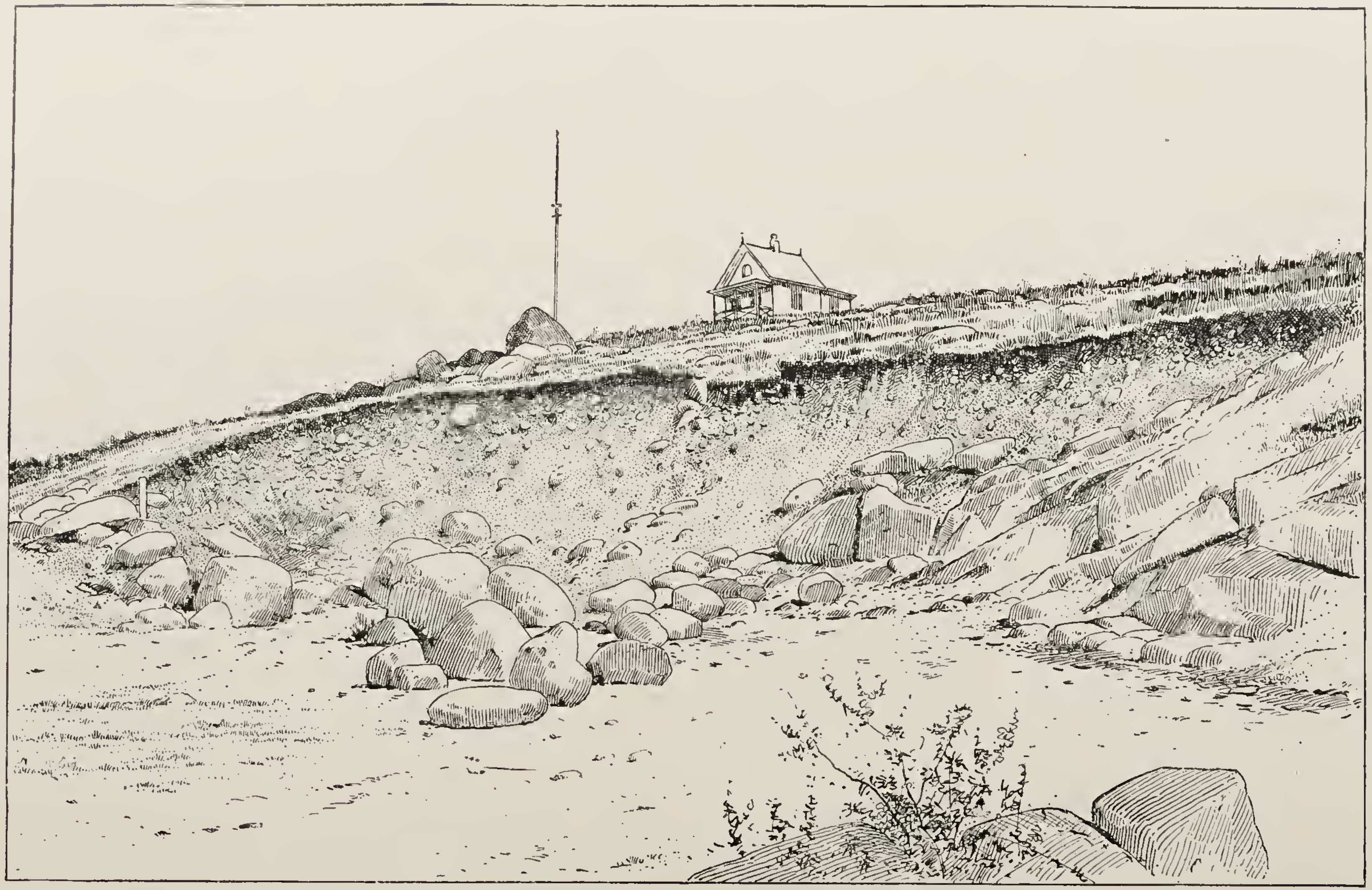
The composition and nature of the materials in the glacial deposits next deserve our attention. Turning first to the shoved moraine, we notice in the first place that the clay element so common in most glacial deposits exists in very small proportion in these accumulations. The whole of the mass has the washed appearance which indicates the extensive action of water at the time of its deposition, an action which has resulted in removing not only the clay proper, but also a very large part of the fine sand. Whatever be the nature of the rocks on which a glacial sheet operates a very large portion of the detrital matter is reduced to the fineness of clay and sand. Observing the eroded surfaces in this vicinity, we find that not less than three-fourths of the material removed from them has come from the scratches and the polishing which the ice applied to the surface, and not more than one-tenth from the plucking out of large bowlders such as now compose at least half of the shoved moraine on this island and the neighboring parts of the mainland. This forces us to the conclusion that the shoved moraine does not include all of the material taken from the rocks over which the ice moved, but only the coarser parts of that matter, the finer having been carried on to more distant points.

In this field as elsewhere we note that the material contained in the shoved moraine has a more uniform character than that which is found in the two classes of kame deposits and in the frontal aprons. Thus the shoved matter of the great moraines consists, so far as my observation goes, entirely of granitic matter and the fragments of dike stones derived from the intersecting volcanic rocks, while in the materials which are found in the kames we note a very considerable proportion of slaty material as well as of crystalline rocks which are not found on the island of Cape Ann or in the immediately adjacent mainland. In the serpent kames the amount of this waste from sedimentary deposits exceeds five per cent.

The explanation of this peculiarity appears to be as follows: The subglacial streams transported the débris rapidly and under circumstances which exempted it from the grinding action of the ice. These conditions of movement enabled the débris to journey for considerable distances without being ground into the state of powder. On the other hand, the shoved moraine, representing material subjected to powerful attrition, has journeyed for a much less distance, and so these streams have brought to this ground a portion of the detritus worn from the sedimentary deposits which occupy the syncline lying to the northwest of the anticlinal axis which constitutes Cape Ann.

In both the shoved moraine and the kame deposits we find by far the greater part of the material to consist of débris essentially like

SECTION OF FRONTAL MORAINE ON SIDE OF WARNER STREET, GLOUCESTER, MASSACHUSETTS.



SECTION OF FRONTAL MORAINE AT ROCKPORT, SHOWING RELATION TO BED ROCKS.

that exhibited on the surface of Cape Ann. This leads me to the conclusion that crystalline rocks of this axis extend for some miles north of the present shore ; a view which is borne out by the character of the rocks exposed in the townships of Essex and also in the southern portion of Ipswich. Both in the kame and in the shoved deposits of this morainal field we observe occasional fragments of gneissic rocks. This waste indicates the existence of a belt of gneiss overlying the injected granites in the country to the north of this district.

FIG. 42. Perched acuminate bowlder on roadside near Rockport Granite Company's quarry.

The bowlders contained in the shoved moraine usually have a very angular aspect. (See Pls. XLVII, XLVIII, and Fig. 43.) Indeed, no morainal matter of this nature known to me in New England, except at certain points in Maine, exhibits the angularity which we find characteristic of the bowlders in this field. They are also noticeable on account of their large average size. As will be seen from the list of the twenty largest bowlders which have been observed, none of them attain dimensions at all comparable to the greater erratics in other districts. Yet, as will be seen from the figures which give the general aspect of the stonier portions of this moraine, the number of the fragments exceeding a hundred cubic feet in volume is very large. We can frequently find on the surface of a single acre as

many as fifty whose average dimensions exceed one hundred cubic feet of mass.

*Twenty largest bowlders.*

| Feet. | | | Feet. | | | Feet. | | | Feet. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 12 by | 16 by | 6 | 15 by | 14 by | 13 | 17 by | 15 by | 10 | 16 by | 14 by | 14 |
| 15 | 10 | 9 | 15 | 15 | 18 | 16 | 18 | 11 | 15 | 18 | 12 |
| 30 | 25 | 18 | 18 | 12 | 11 | 15 | 12 | 9 | 13 | 12 | 10 |
| 20 | 15 | 14 | 8 | 9 | 6 | 21 | 15 | 13 | 20 | 11 | 13 |
| 15 | 15 | 12 | 20 | 9 | 11 | 12 | 18 | 14 | 14 | 9 | 16 |

In the kame deposits we find here as elsewhere that true bowlders are very rare. Those less than a foot in diameter, which have been called by Chamberlain "bowlderets," are not uncommon, though at no point really plentiful. By far the greater portion of the kame material consists of sand, gravel, and pebbles of a rounded form.

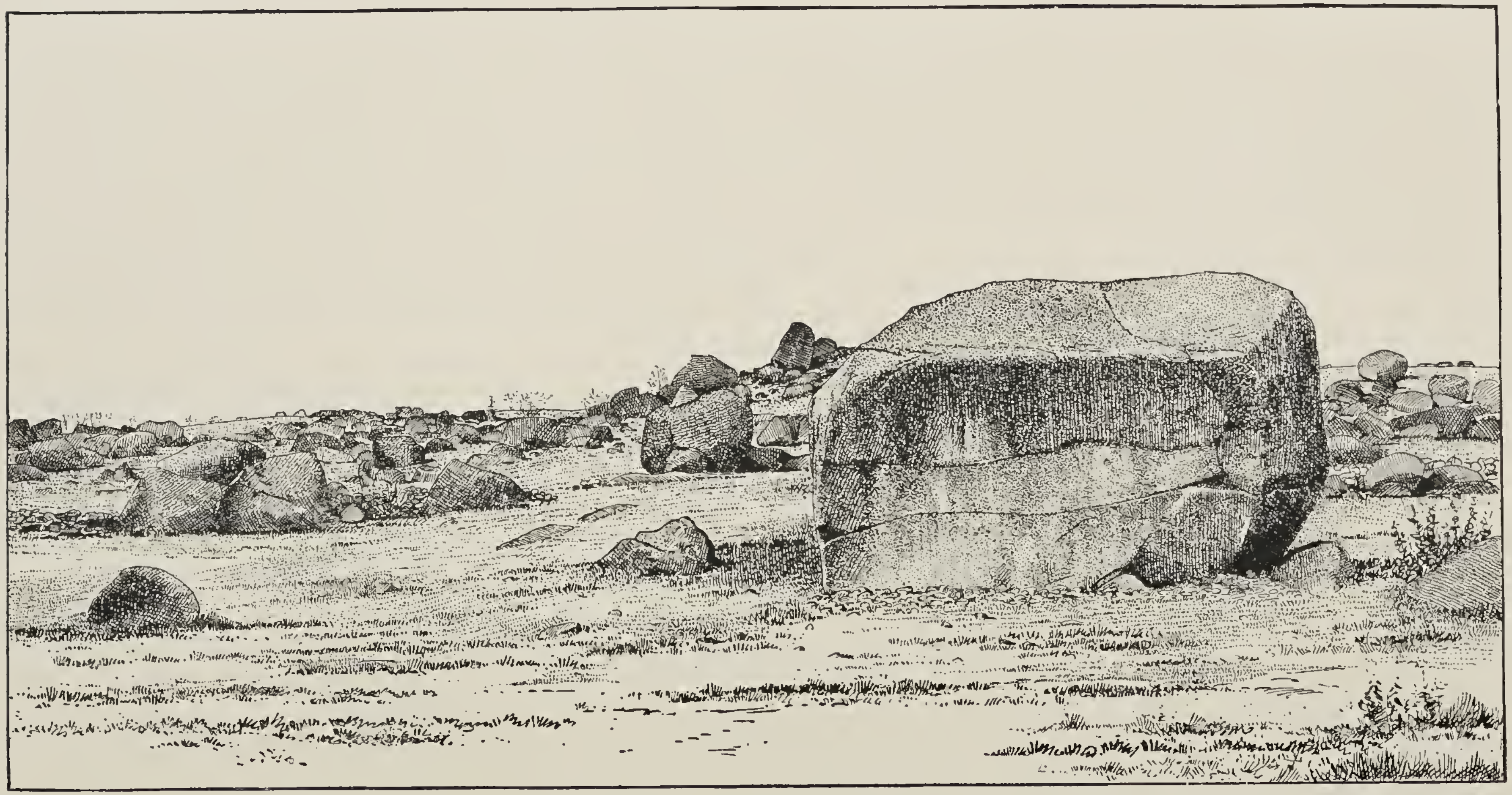
Although the kame deposits are almost entirely limited to the lowlands, we find on the hills of shoved moraine not only the single specimen of serpent kame before noted, but also several small patches of a kame nature, none exceeding three or four acres in extent, and always more or less commingled with ordinary erratics. It is evident that these kame gravels have been imposed upon the surface of the shoved moraine in the form of an overlying sheet.

## DECAY OF BOWLDERS.

The extent to which decay has attacked the materials of these morainal accumulations is exceedingly diverse, and affords an interesting subject for inquiry. Within the mass of the kames or shoved moraine the measure of decay is very small. Only a small part of the material exhibits any indication of disintegration. On the surface of the deposits, however, we find extensive marks of corrosion. This process of decay is indicated in two ways:

In the first place, the superficial bowlders are frequently riven by cracks, which follow the natural joint planes of the rock. These crevices are usually opened by the mechanical action of the frost, though they exhibit a certain amount of decay along the lines of fracture. Perhaps one-fifth of the bowlders are broken up in this manner, thus having the surfaces exposed to corrosion very much extended. The figures given herewith exhibit in a clear way the effect of this development of incipient fracture lines. The facts serve also to show us that at the time when these fragments were rent from their bedding places the joints, which have afterwards developed under the action of frost, were completely sealed, affording no lines of weakness or incipient fracture. (See Pl. XLIX.)

There is another and yet more interesting form of decay which is in its nature more truly corrosive. A walk over the surface of the shoved moraine shows us in particular parts of it, especially near its western extremity on the island of Cape Ann, frequent cases in



NORTHERN SLOPE OF PRINCIPAL NORTHERN FRONTAL MORAINE, WITH PART OF ELEVATED KAME PLAIN, DOGTOWN COMMONS; LOOKING SOUTH.

PIGEON HILL QUARRIES; DIKES CUTTING QUARRY ROCKS; PIGEON HILL DRUMLIM IN THE BACKGROUND.

which the bowlders have decayed to a greater or less degree. Sometimes—indeed commonly at the first stages of this corrosive action—the surface of the bowlder which is exposed to the weather remains in a tolerably solid form, while the internal part of the mass has so broken up that the crystals do not adhere to each other. On the under side of the bowlder, where it is partly supported by other erratics, we may note that it is falling into the state of crystalline gravel. Yet further processes of decay may reduce a great erratic to a mass of disintegrating crystals, containing perhaps a core of material, a small fragment of the original bowlder, all the rest having fallen into small bits. A still further stage in the decay may give us a low mound of detritus, over which the vegetation is gradually mantling. Finally, the place where a bowlder contained a mass of one or two hundred cubic feet may appear as a low grassed mound. On some selected areas in the portions of the field where this action is most evident we find that one-fifth or more of the erratics are in an advanced stage of decomposition.

The surface of the bowlder may remain in a measure intact while the interior is greatly decayed. In such cases we generally find that the surface, though retaining at times its original glaciated character, is much riven by crevices, which indicate a process of enlargement of the mass probably arising from kaolinization of the feldspar which it contains. It is readily observed in the field—indeed it is clear from an inspection of the views given in this report—that the bowlders are divided into two distinct groups, those which decay interstitially and those which remain intact. By far the greater part of the bowlders though—even those of very large size, which have never been protected by any kind of soil coating—remain at the depth of six inches below the surface essentially unchanged by the action of the atmosphere. Often they still retain a surface which has probably been little changed since it was impressed by the glacier. Certainly on the average of bowlders more than six feet in diameter the loss in depth of material has not exceeded two inches, and the mass of the bowlder remains as sound as if it were in the original bedding. In several cases, one of which is shown in the figure (see Pl. XLVIII), we observe that a portion of the bowlder has gone to complete decay, while another part remains essentially unaffected by the corrosive forces. We also note the fact that there is no complete gradation between the bowlders which are perfectly protected and those which are greatly decayed. These facts make it clear that the decay is due to some local peculiarity which is found in certain portions of these granites. At first I was disposed to attribute this peculiarity to the chemical constitution of the mass, but close inspection of the material leads me to the conviction that this is not the true explanation of the phenomenon. It is more likely to be explained by the presence or absence of the peculiar close-set joints, which, as we shall note in

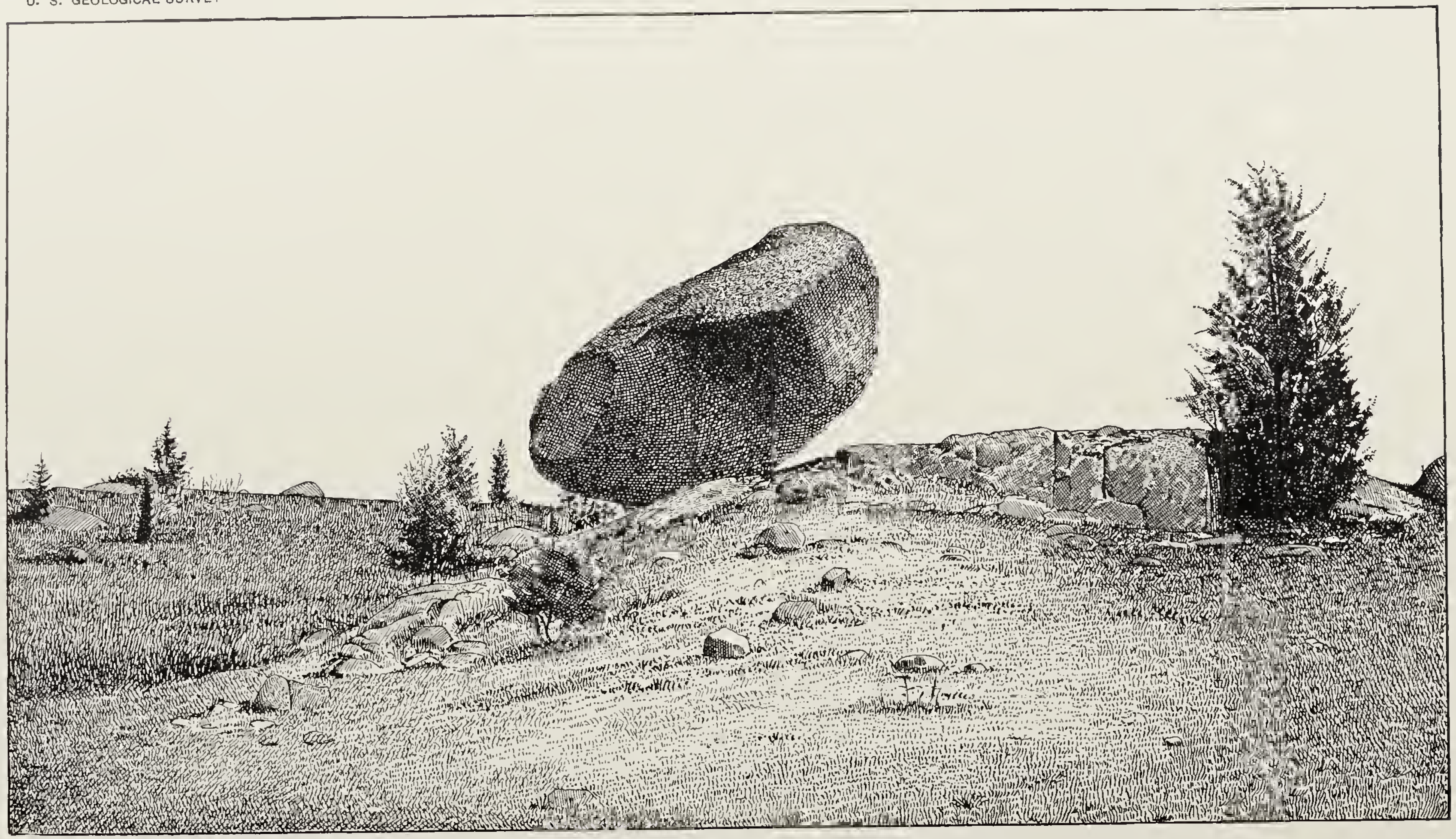
our study of the structure of the granitites, varies remarkably in different portions of this field. These crevices admit the entrance of water into the mass. The action of frost then produces the same effect upon the mass as it does upon rocks which are penetrated by a slaty cleavage; expanding in the crevices, they are forced somewhat apart, and the way for the penetrating waters made yet more open. (See Pl. L and Fig. 44.)

Fig. 43. Bowlder disrupted by action of frost and the roots of trees, midway between Gloucester and Rockport, west side of road.

## AMOUNT OF EROSION DURING THE GLACIAL PERIOD.

The general configuration of the promontory of Cape Ann makes it probable that very extensive erosion has taken place in the mass in relatively modern times. It should be noted in the first place from the map, the accompanying sections, and the general description which we have given of this anticline, that it owes its relative relief to the erosion of the synclinal deposits which lie northeast and southwest of the ridge itself. An inspection of the general geology of this district shows us that the synclines which are found in it are generally deeply eroded. That in which lies Boston Bay is so deeply carved as to form a considerable indentation of the shore. A similiar erosion has taken place in the syncline which lies north of Cape Ann ridge, but owing to the fact that the basin is very extensively occupied by drift accumulations, it does not appear as a considerable bay. Yet if this drift material were removed the sea would penetrate as far up the valley of the Merrimac as Lowell,

VIEW NEAR STONE BRIDGE ON THE LINE OF THE EASTERN RAILROAD, ONE-FOURTH OF A MILE NORTHEAST OF GLOUCESTER STATION, SHOWING SOUTHERN MARGIN OF MORAINAL RIDGE.



PERCHED BOWLDER, 13 BY 8 BY 5 FEET, ON SIDE OF ROAD TO COFFIN'S BEACH; GRANITITE BOWLDER ON BED ROCK.

and would occupy a large portion of the field lying to the south of the Merrimac River. The bay would probably be larger than that of Boston, and its surface would, if the drift were thus stripped, be interrupted by only a few rocky islands.

The contour of the surface of Cape Ann, so far as we may judge of it in the present condition of embarrassment from the drift covering, appears to indicate the development in the preglacial period of an extensive system of mountain valleys such as normally form the headwaters of considerable streams. These valleys have been in certain cases deepened and in others been partly destroyed by the action of glacial erosion. Although I am disposed to account for these depressions on the supposition that they have been in a good degree the result of glacial wear, I am inclined to think that this wear served merely to deepen and in part to change the outlines of the original depressions worn by their water.

The general aspect of this topography leads to the conclusion that it could not have originated with the surface of the country at its present elevation above the sea. It appears necessary to suppose that the base level of the erosion was considerably higher at the time when these valleys were developed than it is at the present day. Not only on Cape Ann, but along the whole of this anticline, we find the lower portion of these valleys passing directly below the level of the sea, the submerged portions having been filled in mainly by stratified deposits formed since the close of the glacial period.

The fluviatile origin of these valleys of the Cape Ann anticline is distinctly proved by the fact that they widen and deepen in the natural direction of the drainage. If they were due altogether to glacial action they would not have this form. Still further, the hypothesis that they were produced by the action of free water is confirmed by the fact that in many cases they cut across deposits of diverse hardness in the manner so commonly shown in the action of streams, but unknown in that of glaciers, except where they are confined by the boundaries of pre-existing valleys formed by free water.

## GLACIAL SCRATCHES.

The character of the rocks on Cape Ann, as well as the extensive covering of glacial waste, makes it difficult to ascertain the movements of the ice during the last Glacial Period. Such scratches as have been observed are marked on the accompanying map. They indicate that in general the course of the ice movement was from the northwest or between that point and north. Here, as elsewhere on the coast, the detail topography of the bed rocks evidently affects the glacial movement, so that without a larger number of observations than it has been possible to make in this field we can not determine the general direction of the flow with much accuracy. Some years ago I made observations upon the series of scratches at a locality

between Pigeon Cove and Folly Cove, which locality has since been destroyed. Observations show two successive directions of glacial scratches, the one trending from northwest to southeast, the other passing from north to south. Of these the scratches extending from northwest to southeast appear to have been the last formed.

Such variations in the scratches I once deemed of importance as indicating alterations in the direction of the ice movement in the later glacial time. I have observed similar cases along the shore from Eastport to New York. I am now inclined to think that the facts are of small value, for the reason that they show only such temporary alteration in the run of the ice currents as might readily arise from the changes in the strains of a body of such a nature moving over a rough area. The surface of rock on Cape Ann exhibits little trace of the strong grooves which form such a prominent feature in many parts of the glaciated district of North America. The reason for this is tolerably obvious. The hornblenic granitites of this area are very hard; as a whole, much harder than the rocks lying to the northwest, which have afforded the erratics that have impinged upon Cape Ann. The result is that the cutting tool, being softer than the substance to which it was applied, has itself given way. The glacial erosion in this field has been effected rather by the plucking out of large fragments than by the removal of the bed rocks in the finely divided form produced by scratching and grooving.

## CARRIAGE OF ERRATIC MATERIAL.

There is a common notion that the drift in New England has generally been conveyed for great distances. The evidence obtained on Cape Ann would of itself be sufficient to disprove this supposition. This evidence goes to show that the detritus in the frontal moraines and till deposits has generally been carried but a very short distance. The average transportation of these fragments probably does not exceed one or two miles. Of the many thousand bowlders which have been inspected probably not more than a dozen are from beyond the field of hornblendic granitite on the island of Cape Ann or the neighboring mainland within a distance of six miles of Annisquam Reach, the exceptional fragments, not amounting to more than a ten-thousandth part, consist of bowlders which were apparently riven from the schistose rocks lying on the north side of the Cape Ann anticline. Two fragments observed, which clearly belonged to the coarse granite, contained large crystals of mica, which is extensively developed in the region about Lowell and Chelmsford. These bits, neither of which exceeds a foot in diameter, may have been carried for a distance of thirty or forty miles.

On Cape Ann, as elsewhere in New England, the kame drift has evidently undergone a more extended transportation than that which belongs to the group of till in the frontal moraine. The kame

PART OF NORTHERN FRONTAL MORAINE, DOGTOWN COMMONS.

(The ungrassed mounds show heaps of crystalline sand left by the decay of bowlders.)

material contains a good deal of waste, perhaps as much as a third of its whole mass, that has evidently been derived from beyond the limits of Cape Ann. The assemblage of materials is substantially that which we find in the drift of the Merrimac Valley. I am inclined to think that a large part of this débris was brought by subglacial streams from that part of the mainland. The proportion of material in the kame gravels derived from distant sources appears to be greater in the case of the serpent kames than in the other deposits of stratified gravels.

## POST-GLACIAL EROSION ON CAPE ANN.

### ATMOSPHERIC EROSION.

The post-glacial erosion of this district may be divided into two classes—that which is due to the action of surface water, and that which has arisen from the work of the sea on the coast line, both at the present level and at times when the shore was higher.

Considering first the atmospheric erosion, we find that in the main it has been exceedingly small. The area of Cape Ann is not sufficiently great to bring about the accumulation of the fluviatile waters in large streams. The considerable thickness of the drift mass in the upper parts of the island causes the discharge of water to be very regular, and the great prevalence of large bowlders restricts the cutting action of the brooks. Owing to the fact that the bowldery drift contains but little clay, the water penetrates deeply into it and is there stored, to be emitted in a very gradual manner. The frontal apron of the moraine lies almost altogether below the surface of the sea. Therefore this region wants the element of a glacial topography which is most readily cut up by flowing water.

The existing streams on the island, all of them of small size, occupy almost altogether valleys that are in no wise due to their own action, but have been formed by the accidents which have determined the position of the glacial drift. They generally lie in the lines between the morainal ridges, or, where those ridges are wanting, in the channels in the bed rock, which were worn to their present shape if not altogether formed, by the action of the ice. At certain points on the surface of the moraine, particularly on the southern slope, though occasionally occurring also upon its northern versant, there are narrow V-shaped valleys, somewhat clogged with bowlders, which appear to indicate the former existence of streams which were much more powerful than those now operating on the surface. I am inclined to believe that these channels may be due to the fact that in the time immediately following the dispersion of the glacial sheet from this surface and its re-elevation the rain-fall was much more considerable than it is at present. It is, however, impossible to make certain that these channels were not formed by tongue-like protrusions of the ice, which scoured away the portions of the mo-

raine which they traversed. It is true we do not find the heaps of eroded material which in other places often mark the action of such protrusions of the ice, but it is likely that these heaps lie beneath the surface of the sea.

On small areas of the frontal apron and kame sands which remain visible on Cape Ann we find a few shallow runnels, which have doubtless originated from the scouring action of the waters which now flow through them. These channels are, however, so insignificant as to merit no particular description. The only noticeable feature concerning them is that they extend to the present shore, with an inclination which shows that they have been lowered below the sea level in comparatively modern times.

## MARINE EROSION.

The erosive action of the sea presents us with much more important phenomena than that which is due to atmospheric causes. Leaving for the present the question of the action of the sea at former levels above its present height, I shall now consider the effect upon the coast line of this district of the waves and the other erosive agents derived from the ocean.

The whole of the shore line of Cape Ann and that of the larger part of the mainland included within this report, except where small parts have been filled in by drifting sand and pebbles, lies upon the hard crystalline rocks which entirely compose the basement deposits of this region. On these rocks the ocean has exercised its usual erosive influence, due to two diverse causes. In the first place, the assault is accomplished by the beating action of the waves operating upon the cliffs by means of the fragments of rock which the surges impel against the shore. The work of erosion has also been greatly aided, at least in recent time, by the action of ice, which forms abundantly along the whole of this coast line, and operates in a way to advance the disintegration of the hard rocks.

The diversity of the effect of the waves upon the shores is very great. The measure of this action is greatly influenced by the structure of the rocks as regards the joint planes or incipient rupture lines which they afford. Where the rock is abundantly rifted, frost, acting upon the water which has penetrated the crevices, as is well known, breaks up the continuity of the mass. Again, the action of the waves is diversified in its measure by the character of the slope with which the land meets the sea. Thus where, as at several points, the shore descends abruptly into deep water, the waves are not armed with detrital matter, which by being impelled against the cliffs, serves to cut away the rock. Such cliffs are usually unaffected by the blows of the waves, and remain essentially unchanged as regards the outlines given them by glacial erosion. Pls. XXXVII and LII show the action of the sea under these circumstances.

POST-GLACIAL TALUS OF GRANITE PORPHYRY AT WEST GLOUCESTER, LOOKING NORTHWEST, SHOWING RAPID DESTRUCTION OF ROCK BY FROST ACTION.

Where, however, the submarine foundations of the cliffs are in water not more than thirty feet deep, such bowldery matter as may lie at their base is within the grip of the waves and is used by them for the assault of the cliffs. At certain points, where there is a compact detrital talus sufficiently near the surface of the water to admit of effective wave action against the fragments which lie on it, the action of the sea is such as to sweep away from the base of the promontory all the masses which accumulate there, and so protect the cliff against the attrition of the waves. The erosive action of the sea is the most effective where, as on the shore just east of Salt Island, the joints of the rock are so disposed that the frost may rive out the fragments and put them in control of the waves. At such point the sea has generally formed a distinct bench in the manner shown in Pls. XXXII and LIII.

Considering the shore as a whole, not more than a tenth of its line exhibits marine benching of a distinct character. On by far the greater portion of the line the original glacial form remains, with the exception that here and there a small portion of the material has been scarfed away by the combined action of waves and ice. Pl. XXXII exhibits the usual manner in which the line of coast meets the sea.

At first I was disposed to believe that the exemption from erosion was due to the fact that the rocks next the shore had originally been protected by a thick coating of drift, upon which for a time the energy of the waves had been expended, but on closer inquiry I find that the morainal matter of the island, though very thick in the interior district, is very thin next the shore. In a word, this distribution indicates that no considerable mass of such material at any stage of the history of the region since the sea attained its present level lay along the coast line. I am therefore forced to the conclusion that the absence of the marine bench is due in part to the brevity of the time in which the sea has operated at its present level and in part to the fact that the attitude and condition of the coast rocks is such as to afford the coasts a large measure of protection against wave action.

Where the original slope of the rocks towards the sea was very gentle, the waves, in place of striking a violent blow against them, slip up over their surfaces, producing a mere swash in place of an effective stroke. In this case the erosion may take the shape of scouring, as is shown on Pls. XXXIV and XXXV. Even where the rocks descend towards the surge with a steep angle, their structure must be jointed in a manner favorable for the action of the ocean surges, and there must be a talus at the proper depth beneath the surface to favor the movement of the erratics when flung by the waves against the cliff. These several conditions do not exhaust the category of the circumstances which affect the erosion of the shore. Where the

rock is much penetrated by dikes, these dikes are almost invariably less resistent to erosion than the country rock which bounds them, so the result is that under the operation of erosive agents—frost and waves—they become chasms, which serve to weaken the coast wall even where it is not otherwise enfeebled, and so bring about an extensive erosion of the shore. Examples of such action are shown in Pls. XXXIV, LIII, LIV, LV, and LVI.

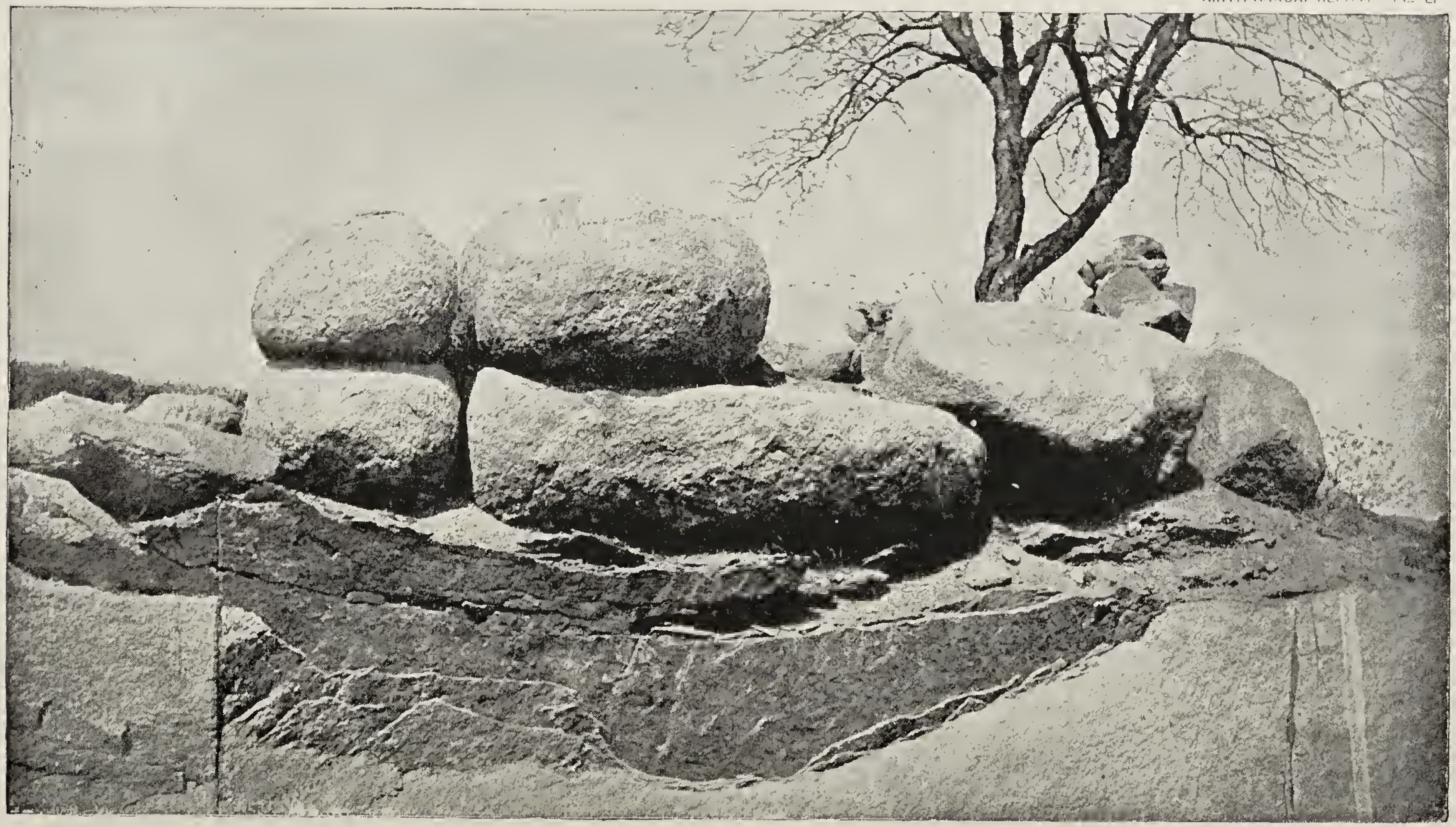
It is now necessary to consider not only the scarf which has been formed along the coast, but also the re-entrants or bays plentifully distributed along its line. Although not so diversified in outline as the neighboring coast of Maine, though formed of similar rocks, the Cape Ann coast presents us with numerous small fiord-like embayments. The reason for this difference is probably to be found in the fact that the strike of the obscurely separated granitic masses on the surface of Cape Ann is nearly northwest and southeast, or in general at about right angles to the flow of the ice; while on the coast of Maine the strikes are more nearly north and south, while the run of the ice is nearer to the meridional line than on this part of the Massachusetts shore. It is clear that the fiords are more easily formed where the strike of the strata coincides with the run of the ice than when these strikes run in the opposite condition.

The fiord structure of Cape Ann is in nowise due to the action of the sea, though these re-entrants have, as we shall shortly see, an important influence on marine action. The fiords of Cape Ann are probably due in part to ordinary fluviatile erosion acting upon rocks according to their resistance and in part to the wearing action of the ice sheet.

### SEA BEACHES.

The effect of the above-described bays is to afford a place of deposit for the material worn from the headlands or brought in from the sea. The structure of one of these beaches is indicated in Plate LVII. On the coast line of Cape Ann and the neighboring mainland included within this report there are about twenty-five of these re-entrants in which beach deposits composed of materials derived from marine action have been accumulated. On the average there is one such pocket to about each mile of shore, and on no part of the marine front do we find these accumulations absent for more than two miles.

The manifest effect of these beach accumulations is in an important manner to limit the erosive work done by the pebbles under the influence of the waves. If a pebble or bowlder is retained on the cliff front until it is ground to powder, all its resistance to the blows is turned to account by the waves in the work of wearing the cliffs; as soon as it is impounded in the beach, it ceases to have any value as an erosive agent. Although it may be ground to powder upon the beach, its force is expended upon the neighboring peb-



DECOMPOSITION BOWLDER IN PLACE, LANESVILLE GRANITE COMPANY'S QUARRY, EASTERN SIDE.

SHORE AT PIGEON COVE, SHOWING EFFECT OF NEARLY HORIZONTAL JOINT PLANES WHEN WORN BY SEA WAVES; LOOKING NORTHEAST.

(The fragments at the top of the slope have been thrown up by the waves.)

bles and not upon the cliffs from which it may have been derived. The difference in the amount of erosion brought about by this variety in the history of a pebble is of considerable importance in the economy of the shore. So numerous are these pocket beaches on Cape Ann, that in most cases the masses of rock derived from the erosion of the cliffs remain for but a short time available as instruments of wear when hurled by the waves; they quickly find their way into the nearest pocket beach. (See Pl. LVII.)

The peculiar salience of the island of Cape Ann favors this rapid impounding of the pebbles. The waves run with considerable energy from a great variety of directions. They are effective on all points from the northwest around by the east to the southwest. Thus, if a pebble is held against a shore having a north and south direction by all the winds blowing from the east, the waves running during the northeast and southeast storms will tend to work it along the coast towards the nearest pocket beach. The result of this action is that the pocket beaches of the Cape Ann district contain a very much larger amount of detrital matter than has been eroded from the cliffs since the sea assumed its present altitude, much being brought from the regions north and south of the district.

### EFFECT OF SEA-WEEDS ON MOVEMENTS OF PEBBLES.

The large amount of the accumulations of impounded matter in the various bays is due in part to the fact that a considerable quantity of glacial detritus has been brought in in the form of pebbles or bowlders, not exceeding a foot or so in diameter, from the deposits of such materials lying upon the sea floor. These deposits, accumulated on the sea bottom, were formed in the main during the time when the shore was at a higher level than at present. At first I was disposed to consider that the material worked in from the sea altogether, because of the fact that the recent elevation had brought the bottom so near the surface that the waves eroded the floor over which they traveled and moved the waste in towards the shore. More careful study has satisfied me that this scouring action of the waves acts only upon the sand and perhaps on pebbly matter less than an inch in diameter. The large ingress of pebbles and small bowlders must be explained in another manner.

The sandy accumulations, particularly the extensive deposits formed in Sandy Bay, on Long Beach, around Little Good Harbor beach, Brace's Cove, and other points of the shore, are clearly due to the scouring action of the waves operating on the neighboring parts of the sea floor. The pebbles, at least those above an inch in diameter, are in the main brought to the coast line in a manner which I will now describe.

The bowlders and larger pebbles, as they lie upon the sea bottom, not only by their weight oppose the movement of the waves which

tend to urge them towards the shore, but they are attached to the bottom by the adhesion naturally resulting from long continuance in their place. Even where the waves are strong enough to roll them if they were free from these attachments they remain immovable. It is to the growth of sea-weed upon their upper surfaces that we owe in most cases their detachment from the bottom and their ready transportation to the shores. When the sea-weed becomes attached to these pebbles its continued growth leads in time to the separation of the pebble from the bottom. This is brought about partly by the impulse to float due to the relative lightness of the plants, and in a larger measure through the pull which the waves are enabled to make on the expanded fronds of the sea-weed. When, in time, through the growth of the plant, this pull becomes strong enough to detach a pebble from its ancient fastenings, it rises a little way above the bottom, sometimes floats freely, sometimes just rests on the sea floor, and so impelled by the waves begins the journey towards the shore, which becomes more rapid the shallower the water to which it attains. Finally, it is brought into the mill of the surf; it then in most cases becomes separated from the plants which brought it ashore and appears as an ordinary pebble upon the beach.

Choosing a time when the surf is high, we may note a great quantity of sea-weed on the beach. Each of these weeds shows in its expanded root-like base that it has recently been severed from an attachment to some rock. Occasionally we find a pebble to which the sea-weed is still clinging. These are rarely abundant, for the reason that the separation, as before noted, has usually taken place by the pounding of the surf; but at times it is possible to gather a bushel of these pebbles still attached to the sea-weed within the distance of one hundred feet of shore line. If an observer in a time of storm will follow a retreating wave outward, so that he may have an opportunity to observe the inner face of the surf wall when it rises in its steep form a moment before the overturn of the wave, he will, if quick-eyed, be able to note in the transparent water many of these sea-weeds as they are lifted to a vertical position by the uprising of the wave. Furthermore, if he will journey in a boat beyond the surf line, he may find many of these sea-weeds floating with the tops at the surface of the water, each bearing at the base a pebble or large shell, which have been plucked from the bottom some distance from the coast line.

Although the quantity of this pebbly matter brought in by any one storm is not very great, the contribution is repeatedly made, so that during each year perhaps in a score of storms some tons of bowlder material comes upon the shore within the length of a thousand feet. A portion of these bowlders with their floats of sea-weed are of course driven against the cliff portion of the shore, where the

WORN-OUT DIKE ON SHORE OF PIGEON COVE, SO-CALLED "CHAPIN'S GULLY;" LOOKING SOUTHEAST.


SEA-CAVE ON SHORE OPPOSITE SALT ISLAND, SHOWING PROCESS OF WAVE EXCAVATION ON JOINTED ROCKS.

bowlders serve for a time in the work of the waves, but they shortly find their way into the re-entrants in the manner before described.

Not only do these sea-weed-borne fragments contribute much, perhaps a greater part, of the waste to the beaches, but in certain cases they form considerable pebbly islands off the coast. Thus, Milk Island, south of Thatcher's Island, though its central parts are of bed rock, is mainly composed of these pebbles, removed from their bedding by the sea-weed and intercepted on their journey towards the mainland by the shoal formed by this glacially rounded mass interposed in their path.

### RATE OF WEAR OF PEBBLES.

The rate at which the beach pebbles wear varies of course with their size and with reference to the conditions of exposure to the surge. The smaller the pebbles, the more rapidly they are worn, for the reason that they are more readily stirred by the action of slight waves. Thus, pebbles two inches in diameter are set in motion even when the sea is nearly calm, while those a foot in diameter are probably not in motion for more than one-half of the year, and those which exceed two feet in diameter are only knocked about in the greater storms. We must reckon on the fact that the larger pebbles strike harder blows than those of small size, but I am inclined to think that the rate of wear between those one foot and one inch in diameter is generally proportionate to the difference in the mass.

It is interesting to note that no considerable part of the mud produced by the wearing of the pebbles on these beaches remains visible. By far the greater portion is evidently drawn away into the depths of the sea by the undertow which during high winds prevails along every shore.

The wearing action even on the larger pebbles is evident from observations which can readily be made on the masses of riprap used for the defense of the moles which inclose the small artificial harbors between Rockport and Pigeon Cove. Although originally of very angular forms, such as plentifully occur in the quarries, an exposure to the full beating of the waves serves even in a single year to bring about a considerable rounding of the mass. In ten years they commonly wear away to the rolled form so familiar in our beach pebbles. Under favorable circumstances it is evident that the wear upon the pebbles amounts on the average to several inches per annum. We thus obtain a rough measure of the rate at which the surges are able to bring about the wear and consequent rounding of detached masses.

It should be remarked, however, in this connection that the rate at which these artificially exposed angular masses become rounded is somewhat greater than that which occurs in masses detached from cliffs, for the reason that under the conditions in which they are

placed the sea has a peculiarly favorable opportunity for attacking them. Their position is extremely exposed, and many fragments are associated together in a manner which causes them to rub against each other more energetically than is possible at the foot of an ordinary cliff.

In seeking to find stone suitable for quarrying purposes, explorers have opened small excavations on most all the headlands around the periphery of Cape Ann. These have discharged into the sea a large quantity of angular blocks, which have been moved along the escarpments until impounded in some beach pocket, where they are now in the process of rapid erosion. Blocks of this nature can be readily separated by the eye from those which have been ruptured from the cliffs by the action of the waves and frost, for the reason that bowlders formed entirely in the natural way are generally discolored by decay to a greater depth than corrosion has penetrated, while those formed in an artificial manner usually retain the blue-gray hue of the ordinary quarry stones.

Using this means of discrimination in order to separate the artificial from the natural pebbles, the observer can readily make an eye-estimate as to the relative amounts of bowldery matter formed by natural and artificial means. He will perceive that the amount of detrital material formed in the natural way on rocky shores is often less considerable than that contributed by the process of quarrying. A number of little pocket beaches filled with bowlders which are found along the coast, especially between Loblolly Cove and Halibut Point, are almost entirely composed of rounded waste from the quarries.

The ineffectiveness of marine action on certain parts of the shore is particularly conspicuous. Thus near Pigeon Cove (See Pl. LII) it is evident that marine action has since the Glacial Period not removed in average thickness more than one or two feet of the rock which forms the shore line, while in the region immediately south of Bass Rocks the erosion is perhaps thirty times as great. The cause of this variety in the amount of wearing is readily found in the difference of original inclinations of the shore towards the sea. At Anderson Point the rocks have a very gentle slope towards the waves. The surges working on the coast line slip up over this slope and expend their energy in lifting the mass of water above its base. Where, as at Bass Rocks, the shore meets the sea at a steeper angle, the direct blow of the waves is struck against the cliffs and operates much more effectively.

The concomitant in this action is found in the extent to which the shore at these diverse points is affected by dikes which are readily worn out by the water. Near Bass Rocks and also near Straitsmouth Island the dikes are numerous and readily attacked by the waves. (See Pls. XXXIII, LIII, LV, LVI.) When the dike material is re-


CHASM ABOVE HIGH-WATER MARK, FORMED BY EROSION OF DIKE, ROCKPORT POINT, EAST SIDE.

moved steep cliffs are left on either side in positions to be open to the assault of the sea. This effect is well seen on the shores just inside of Straitsmouth Island, known as Gully Point, where the dikes, being rather softer than elsewhere, have been deeply excavated by the waves.

### DECAY IN ROCKS IN PLACE.

I have already noted the fact that the bowlders contained in the frontal moraines are in many cases extensively decayed. So far has this decay gone, that I have often found a bowlder which was originally six feet in diameter represented by a low mound of angular sand upon which the vegetation finds root. The same decay, though in much less striking form, is exhibited by the rocks in place. So far as my observations have gone this decay is limited to the granitites, not affecting the dike stones. It generally occurs within 10 feet of the surface in sections where the rocks lie in a position which favors the penetration of surface water. Finding its way along the joints, the water furnishes conditions of corrosion, so that from the joint planes the decay penetrates to a greater or less distance into the unrifted portion between the fracture planes. A portion of the material is reduced to the state of sand, another part is merely discolored and weakened by the oxidizing process. (See Pl. LI.)

In passing, I may remark the fact that the considerable penetration of this form of decay since the Glacial Period affords, when taken in connection with the decayed bowlders above referred to, important evidence as to the depth to which the glacial erosion operated during the last ice time. It is evident that the decayed bowlders were not affected by the corrosive process before they entered on their journey towards the front of the ice field. The strains to which they were subjected in that journey would have led to their destruction if they had not been of very solid rock. In order to obtain bowldery matter liable to corrosion and at the same time not decayed, the glaciers must have removed all the superficial parts of oxidized rocks which existed on the surface at the time their work began.

There can be no question that the decay in certain of the bowlders is generally more complete than that which has occurred in any rock in place. This is readily explained by the fact that the bowlders are much more favorably placed for the work of corrosion than are any portions of the rocks in their original position.

## RECENT CHANGES OF LEVEL IN THE CAPE ANN DISTRICT.

As one of the principal objects of the series of monographs descriptive of different parts of the Atlantic coast which I have undertaken is to determine the recent changes of level which have occurred along that shore line, I turn with interest to the study of

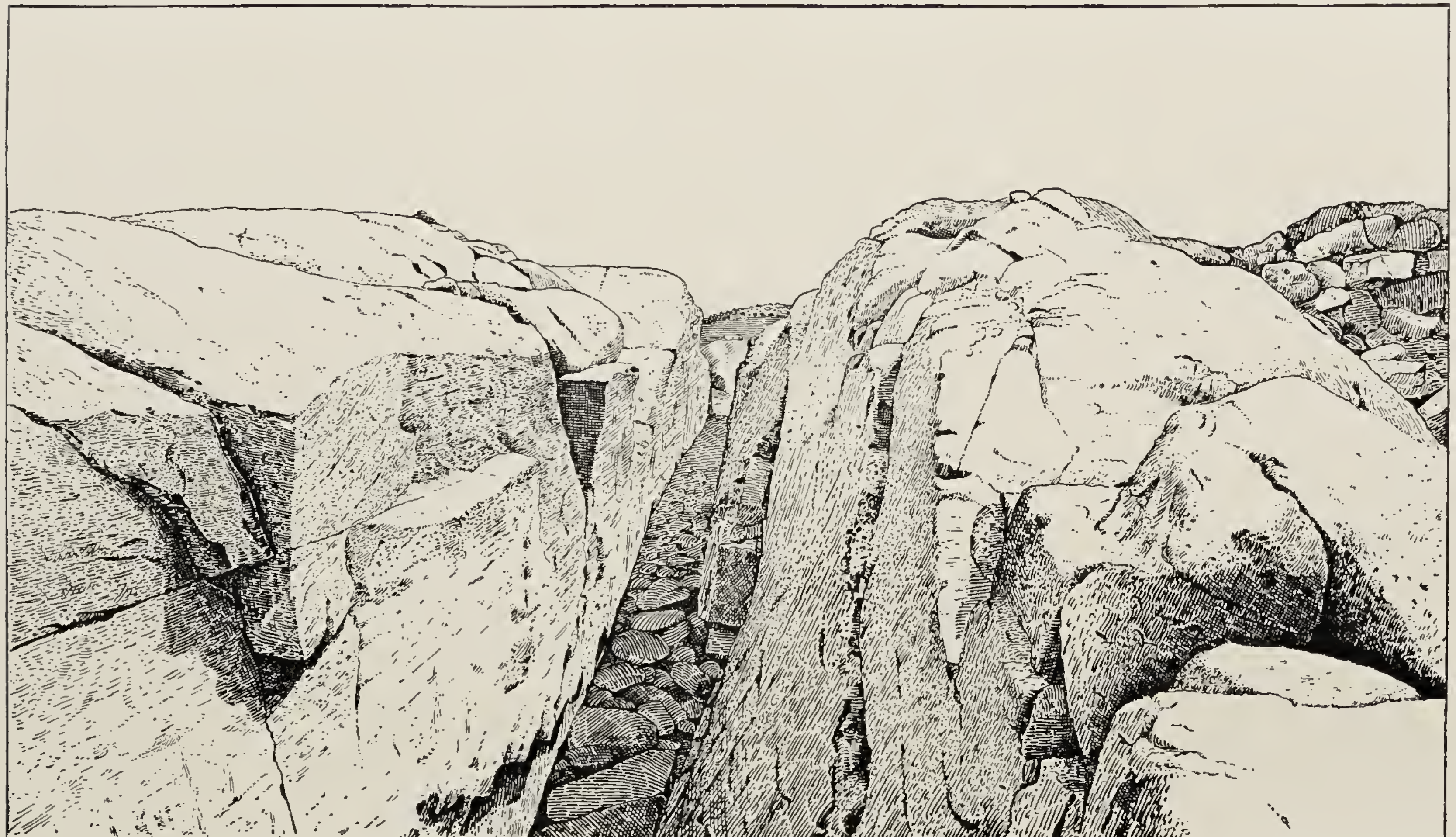
post-glacial changes in the altitude of the land on this part of the coast.

My studies on the island of Mount Desert have apparently shown that on that shore, one hundred miles north of Cape Ann, very remarkable alterations of level have taken place since the close of the Glacial Period, or at least since the disappearance of the ice sheet from that portion of the coast. On Mount Desert the evidence indicates movements of elevation since the disappearance of the ice, and on other parts of the shore from Portland southward the evidence is to the effect that the movements have been in part in the direction of subsidence and in part those of elevation. On Mount Desert itself all the observed facts indicate elevation alone, though, as remarked in my memoir on that island, published in the Annual Report of the Director for 1886-'87, the shore of Mount Desert is very unfavorably placed for the preservation of evidence of subsidence. It may therefore well be the case that subsidence has taken place there, though the proof of it is wanting.

### EVIDENCES OF RECENT SUBSIDENCE.

Considering first the evidence of recent subsidence, we find on Cape Ann a limited but important set of facts which bear on this problem. On the east shore of the island, at a point indicated on the map by the words "submerged forest," near the isolated mass of rock known as "Briar Neck," we find between high and low tide mark a number of tree stumps with their roots still fixed in an ancient soil in their normal positions, which clearly indicate a very recent subsidence, amounting to as much as four feet of actual height. These interesting remains lie in a position that appears to me to exclude any other hypothesis than that which assumes that the surface on which they stand has been lowered by a downward movement of the subjacent earth. They stand upon a nearly plane surface, in front of a low beach wall of sand and pebbles; behind them lies a considerable area of marine marshes.

In this and the numerous other cases of depressed forests which occur on our shore the hypothesis which has been suggested, that the sea has undercut the soil in which the forest grew, thus lowering it beneath its present position, appears to me quite untenable. The waves strike against this shore with great energy. As soon as the stumps are separated from the enveloping beach sand they are quickly cut away by the surf. The process of undercutting which should lower the forest bed to the level of the waves would necessarily lead to the immediate destruction of the deposit. Moreover, here as elsewhere, we ask the question as to where we may now find this process of undercutting in operation? If we account for the submerged forests on this theory, we should be prepared to show



DIKE CHASM ABOVE HIGH-WATER MARK, WEST SIDE OF ROCKPORT POINT, SHOWING DIKE MATERIAL CONVERTED INTO BOWLDERS.

along our extensive shore line instances in which it may be seen in various stages of accomplishment. My studies on the Atlantic shore line have shown me in a very detailed way the greater part of the coast between Eastport and New York. At no point have I ever observed any process of undercutting the forest such as this hypothesis demands. I therefore take this example as well as the numerous others which occur along our coast as complete evidence that a recent subsidence of the shore or elevation of the sea to the amount of several feet has occurred in very modern times.[1]

So far this is the only instance on the periphery of Cape Ann where I have been able certainly to ascertain the existence of submerged forests. It is to be observed that the conditions which permit the preservation and the re-elevation of such deposits are peculiar. Except where shown by artificial excavations, we find them at points where the sea cuts through a mass of dune sand such as forms along the coast line or sand of the beach, in which the remains of the forest lie buried. Where a beach is gaining on the sea, as is the case with most of the sand beaches of the Cape Ann district, we can not of course expect to gain any sight of a submerged forest existing at that point. It is only where the sand beaches are retreating landward that the buried forests are likely to be exposed to view.

Although the existing remains of the submerged forests above referred to prove at most a subsidence of four or five feet, there is good reason to believe that the total amount of this depression has been much greater than is indicated at this place. In the adjacent waters of Massachusetts Bay we find on the flats of Lynn Bay occasional stumps of trees faintly exposed to view through the water at the lowest run of the tides, and in Cambridgeport, Mass., I obtained the stump of a tree in position seventeen feet below high-tide mark, or about seven feet below the lowest tides of the present day.

## EVIDENCES OF RECENT ELEVATION.

The evidences of recent elevation along the coast of Cape Ann are extremely obscure, at least when compared with the proof of such movements afforded on the island of Mount Desert. The proofs which we may obtain of the temporary sojourn of the sea at heights above its present level fall into the following classes: First, we may have a surface swept clear of all but the larger bowlders in the fashion shown along the present shore line. This effect may be looked for even where the sea operated on the surface for a very brief time, provided the drift coating was not extremely thick. Where the surface has been scoured in this fashion by the waves the drift is not only removed from the convex portions of the area, but is

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[1] See memoir on Martha's Vineyard, Annual Report U. S. Geol. Survey for 1885-'86; also report on Geology of Nantucket, Bulletin of Geological Survey, No. 53.

scoured out of the crevices and clefts of the rock, in which it is sure to remain where the waves have not washed their surfaces. Thus, such rock areas as are shown in Pls. XXXIII, XXXIV, LVIII, LIX, LX, LXI, and Fig. 45, clearly indicate the action of the waves by the complete removal of the detrital material which has accumulated at their base in the form of a gently sloping talus.

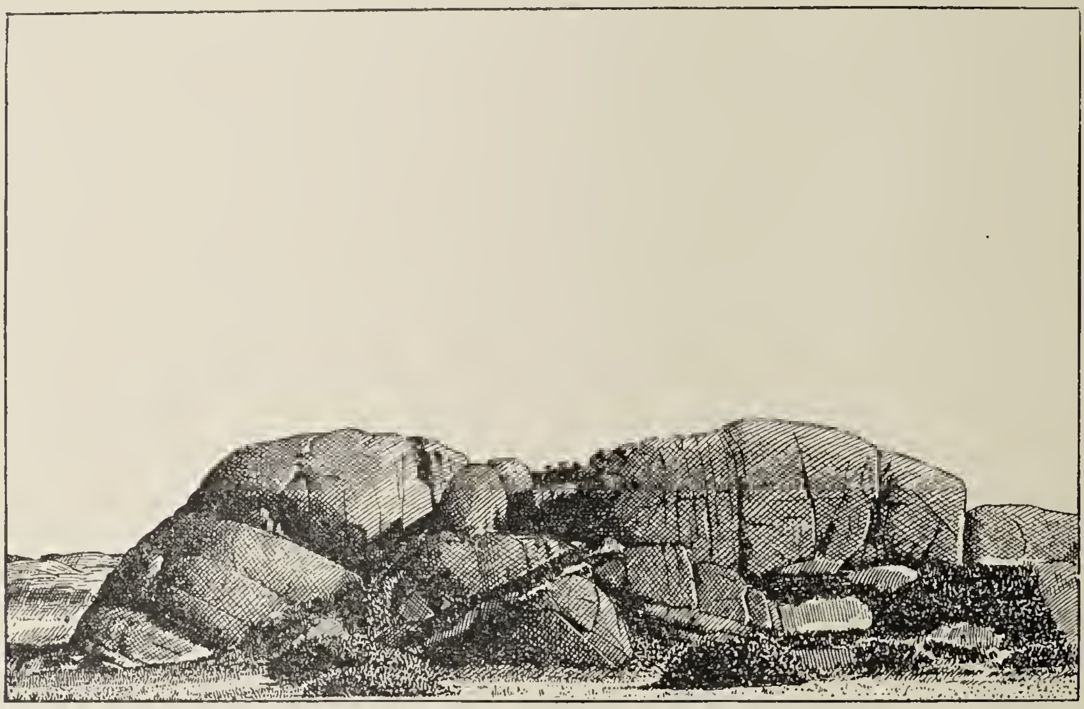


FIG. 44. Eastern Point, 40 to 70 feet above sea; ledges from which drift has been completely removed by marine action.

Where the waves operated for a considerable time on the surface, we may expect to find the softer parts of the rocks, the portions enfeebled by the numerous joints or by dikes, distinctly excavated, forming chasms or sea caves according to the direction in which the lines of weakness extend. The amount of this distinct cutting action depends largely on the slope of the rocky surface; as we see along the existing shore where this slope is very gentle the sea has practically no cutting power, whereas if the original slope was steep, the cliff and bench, such as shown in Pl. XXXIII, quickly formed. Again, where the process of erosion has continued for a considerable time the waste removed from the salients will be accumulated in the form of beaches in the interior portion of the re-entrant angles. The accumulation of beaches appears to require a more continued action of the sea than is needed for the formation of the other indices of marine action.

It is important to notice that where the drift coating is thick the natural processes which affect the movements of the soil after the passage of the sea from the surface at once operate to destroy all marks of wave action upon the surface. Although a scarf may be cut in the detrital matter, and perhaps in the solid rock upon which

NORTHEAST END OF BEACH NEAR CAPE HEDGE, MILK ISLAND IN DISTANCE, SHOWING TYPE OF BOWLDER BEACH.

it rests, no sooner does the sea disappear than gravity, aided by the action of frost and by the action of trees which by their expanding roots shove the masses downwards and in the cases where the trunks are overturned by winds displace large masses of the material, serves quickly to heal the slope, so that in a short time the bench may be entirely effaced. This action is so manifest on the surface of Mount Desert that I have long since ceased to put much trust in indications of marine action derived from faces of loose material, though it can not be denied that traces of such erosion may be found on the flanks of some of our drumlins.

### HEIGHT OF SEA SINCE GLACIAL PERIOD.

The imperfect evidence which I have succeeded in obtaining on the Cape Ann district, serving to show the action of the sea above its present level, is limited to 150 feet above the present tide mark. Within this section the evidence consists mainly in the removal of the drift from extensive areas of rock on which it was originally thinly distributed.

Where, on a large area, we find no glacial debris except occasional bowlders with the dimensions of those which now resist the action of the waves along the shore, we may be pretty sure that the sea has not acted, and this for the following reason, viz: On any surface which has been glacially eroded, as has the whole of the Cape Ann district, the ice as it passed away must have left a thin sheet of detrital materials. Even where the surface was more or less washed by the melting waters of the retreating ice, the crannies and hollow places of the rock surfaces would necessarily contain a good deal of glacial waste which would escape removal. I am unable to explain a complete scouring of the surface, such as is exhibited in Pls. LIV and LIX, without having recourse to wave action.

The argument in favor of wave action becomes stronger when, as before remarked, we find the steeper faces of the rocks worn by the work of the sea in the fashion that can be effected only by the battering action of the surges. It is usually easy in case of any strongly projecting mass of glacially eroded bed rock to determine which of its several versants would have received the direct beating of the waves and which would have been protected from their action. If, on the faces which would have been exposed to the ocean surges at the time when the sea is supposed to have stood at the higher level, we find a recognizable amount of marine erosion, we substantiate the hypothesis which supposes the original greater height of the sea.

Beginning at the present level of the sea, we first note the fact that the recent slight uplift has raised the shore to the amount of something less than ten feet. This is shown by the conditions prevailing in many of the clefts along the shore which have evidently been eroded by wave action, though the principal parts of ascending

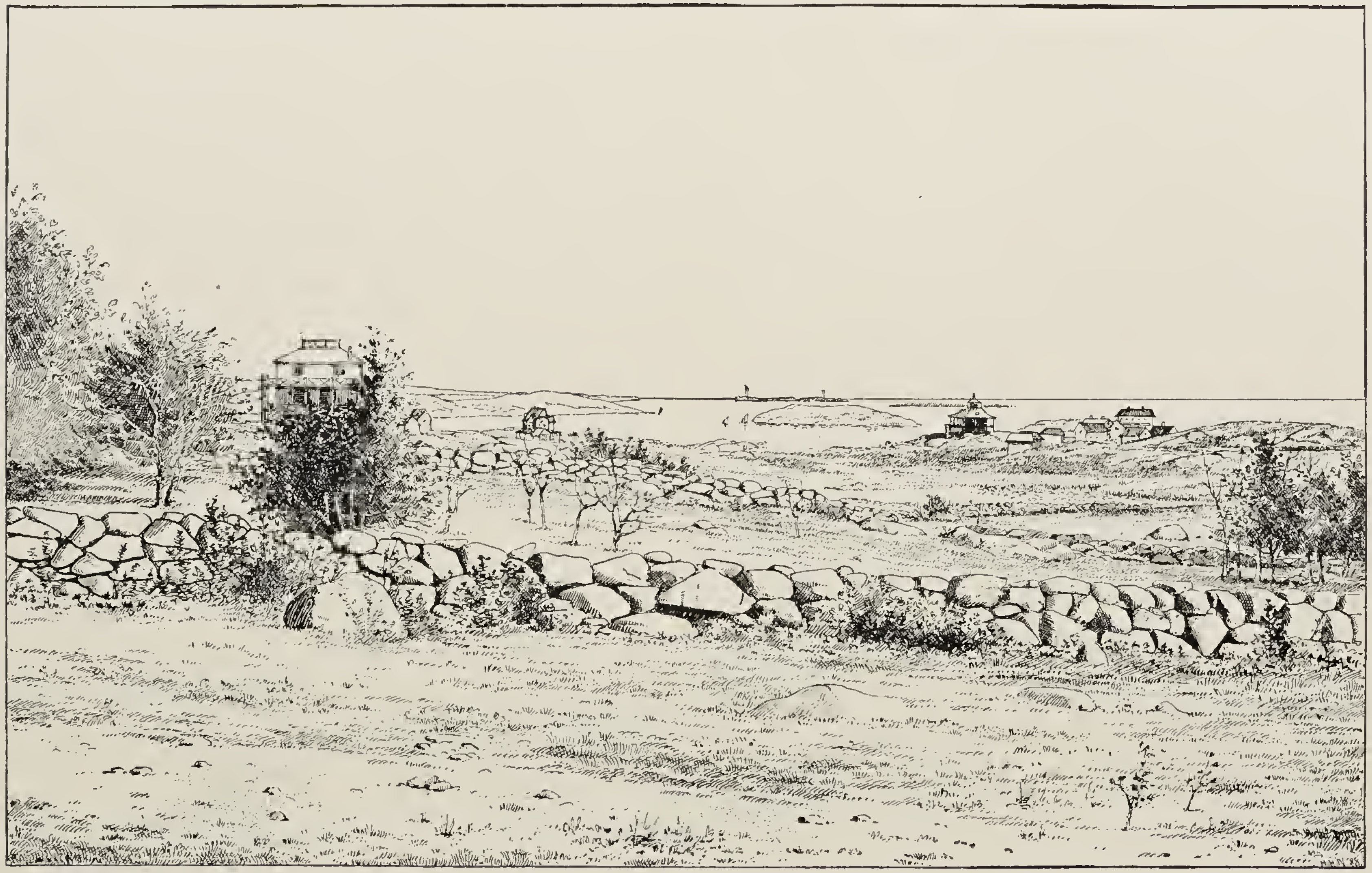
floors are at present sufficiently above the existing plane of the sea. Thus in Pl. LXII we see an example of the cases of chasms which are evidently due to wave action, but which have parts of their beds now much above the water level. Furthermore, it appears evident at various points on the shore, as is exhibited in Fig. 45 and Pl. LXI that the rock surface has been swept by waves when the sea had access to somewhat higher points than it has at present.

At first sight I was disposed to attribute this difference in the action of the waves to the gradual shoaling of the water of the coast and the consequent failure of the waves to attain the shore when they were operating with their utmost energy. A careful consideration of the facts, however, has satisfied me that this is not a sufficient explanation of the phenomena, for the reason that the evidence of uprising is conspicuous even on those parts of the shore where in the heaviest storms the waves do not break until they touch the shore line. Thus in the case of the excavated dike on the east side of Gloucester harbor, shown in Pl. LXII, the waves never have any great energy and yet they have clearly operated to excavate the dike to a height of about ten feet above the level at which they at present operate.

Passing upwards, we find the next level on which marine action is indicated at a height of about forty feet above the present high tide and thence upward to the height of about seventy feet. The operation of the sea at this height is more or less plainly shown around the whole of the periphery of Cape Ann, wherever the surfaces are well fitted to retain indications of marine action. Thus in Fig. 45, on the east shore of Gloucester harbor we note a portion of an extensive field which has been thoroughly washed by wave action and the crannies cleared of all save a few tightly wedged bowlders and the lines of weakness to a certain extent developed in the form of sea caves and clefts.

The next level exhibiting distinct marine erosion is at the height of from about one hundred to one hundred and thirty feet. The indications of marine action at this height are more distinct upon the eastern and southern portions of the island than upon other parts, for the reason that the rocks stand in more favorable positions for the exposition of such action and they are less thickly covered by a drift coating which might, as before suggested, conceal the effects of the waves. Above the height of 130 feet nearly the whole of the island is thickly covered with the morainal matter. The extreme instability of the slopes cut in this material is well shown by the constant movement of the detritus where it is exposed at steep slopes in existing railway cuts. A few thousand years of exposure, especially if the surface becomes subjected to the action of strong roots and the overturning of trees, would clearly serve to efface marine scarfs or other evidences of shore-line action.

The very fact that morainal drift on this island is mainly limited



VIEW NEAR BASS ROCKS—SALT ISLAND, MILK ISLAND, AND THATCHER'S ISLAND IN THE DISTANCE—SHOWING GENERAL CHARACTER OF SURFACE; HALF BARE ROCK, HALF TILL.

to heights above 100 feet is of itself evidence of a certain value to show the action of the sea. (See Pl. LXXV.) There is no other way in which we can so well account for the limitation in distribution of this drift as by the supposition that it has been worn away at lower levels by marine action, taking effect in the form of waves or of shore ice.

Below the general surface of rocks apparently wave swept, between the present level of the sea and the height of 140 feet, we almost invariably find a gently inclined talus, composed of materials which, we may presume, have been swept from the bared surfaces. Wherever we are enabled to get any section of this detrital matter it appears to be rudely stratified, much as the waste which has lately been stripped from the shore line is laid down at the foot of the sea cliffs.

At first sight the observer may be surprised to find that these taluses have not their upper edge at a regular height above the level of the sea; in other words, they are not beaches formed at the foot of cliffs but under-water taluses, having only a partial likeness to the beach structures. If he will observe the existing shore line with the plummet to determine the depth of the taluses below sea water he will find that they exhibit an irregularity like that which we find at higher levels where we have assumed that the sea operated.

The only difficulty which we encounter in supposing that the phenomena in question are to be explained by marine action at higher levels is due to the fact that we fail to find distinct beaches of characteristic shape lying in positions corresponding to those they now occupy at lower levels. So far I have been unable to trace any unquestionable beaches which were formed during the time when the sea should have occupied the higher levels where I am disposed to believe it has been. The failure to find these structures is certainly an argument against a long continued action of the sea at any point above its present height. A careful study, however, has convinced me that beaches are not quickly or rapidly formed by marine action, but they represent the slow operation of forces which can come into action only under peculiar circumstances. Replacing the sea along this shore at the height of 100 feet in imagination, we note that the considerable depth of water of that shore line would make it impossible for the waves to come into possession of any large amount of detritus. The fine matter in moraines is relatively small in quantity, and the large bowlders are hard to move in the manner necessary to form beaches. All save the largest of them would quickly be dragged into the troughs of the shore, but it would evidently require a considerable time for the formation of any distinct beaches in the reentrants. At present a greater part of the pebbles which are found on such beaches are brought in by the action of marine plants, which, presumably, did not exist along this shore in the closing stages of the ice time. The sands of the sand beaches are heaved in from the

seaward, owing to the fact that the water in the existing condition of the levels is tolerably shallow. With 100 feet added to the depth, they would be as completely wanting as they now are on many parts of the coast of Maine. It is only the beaches composed of large rounded pebbles, exceeding six inches in diameter, which we could expect to find along the shore line when it was at higher levels, and such accumulations never have the characteristic form of ordinary beaches.

There are many points about Boston where artificial scarfs such as those made by roads have been formed on slopes of drift materials and allowed by the abandonment of the way to return to a state of nature. Studying such localities, we observe that the action of frost and rain serves in the course of a score or two of years to destroy most of the superficial indications of such an excavation. Even after twenty years, in the case of scarfs which have been exposed in a steep wall three or four feet high, the effect of the cutting is very faintly indicated. It is impossible that such indentations would survive the processes of nature for as much as a thousand years on an ordinary surface. It is a noteworthy fact that on Mount Desert, where as noted in my report (loc. cit.) the old sea levels though distinctly indicated by excavations in the jointed granitic rocks, are rarely manifested in the detrital materials, only at altitudes within 100 feet of the sea level and in places where the detrital materials are more abundant than at any point on Cape Ann, do we find the marine action manifested in the form of beaches. Thus, on the periphery of Mount Desert, which has an extent of from 50 to 60 miles, there are but two places in all the ancient shore lines, having together a length of less than half a mile, where it is possible to determine the existence of sea-worn gravels disposed in their characteristic form. So it is hardly a matter of surprise that we should fail to find them on the much smaller area of Cape Ann, where the detrital matter is less suited to form beaches. Therefore, in endeavoring to ascertain the former presence of the sea at higher levels, I have relied upon the evidences of the scouring action of the waves and the indentations which they have produced on the bed rocks rather than upon the action exhibited by detrital materials.

### DUNES OF CAPE ANN DISTRICT.

We may here note certain interesting features connected with the dune deposits which occur in the Cape Ann district. This portion of the shore of New England is interesting for the reason that it is one of the northernmost points at which extensive duning occurs, it being part of a field occupied by deposits of this nature extending from the northern point of Cape Ann to Portsmouth, N. H. (See Pl. LXIII). On the island of Cape Ann the most important dunes occur on the north shore and upon the east face of the island near

DIKES CUTTING HORNBLENDIC GRANITITE; BASS ROCKS.

Long Beach. Those near Long Beach belong to the ordinary category of shore dunes, which are in the process of growth at the present time.

On the north shore of that island we have a series of these dune deposits extending from near Halibut Point to Annisquam harbor, which are particularly interesting for the reason that they are evidently due to some conditions which are not in operation at present. All these dunes on the northern face of the island have long been grassed, and there is no indication that sand is now coming ashore in sufficient quantities to produce deposits of this nature. The water of the north shore is so deep that only very small amounts of sandy matter are from time to time scoured up among the rocks, yet it is evident that in a recent period the amount of sand yielded to the wind was large. The only way in which I can explain this peculiar feature is by supposing that at a time before the last subsidence, indicated by the submerged forest before described, this north shore was sufficiently elevated to afford sand beaches along the coast from which these dune sands have been swept inland.

In passing I may remark that the singular occurrence of what appear to be dune sands at various points remote from the present coast in Massachusetts and Rhode Island may perhaps be explained by the former presence of the sea at higher levels along the shore. On the mainland opposite Annisquam village, the point known as Coffin's Beach, there are very extensive dune deposits which are in the process of active construction. There is a tradition to the effect that two small farms which were tilled during the last century have been overwhelmed by the southern march of these sands. The genesis of these dunes is easily to be understood. The shore from Coffin's Beach to Newburyport trends in a general northwest direction, the whole of this coast constituting a great pocket beach on which the sands tend to move southwardly under the influence of the waves, their further southward journey being hindered by the salient of Cape Ann. The wind frequently blows in dry periods from the northwest and sweeps the beach sands southward to the bottom of the recess and accumulates them in these dune hills. It is likely that the southward movement of these sands was greater in the period of elevation just referred to than it is at present. Despite the evidence of the tradition which goes to show that these sands have recently advanced to the south, I am of the opinion that the accumulation of the deposit mostly took place in ancient times.

## MARSHES.

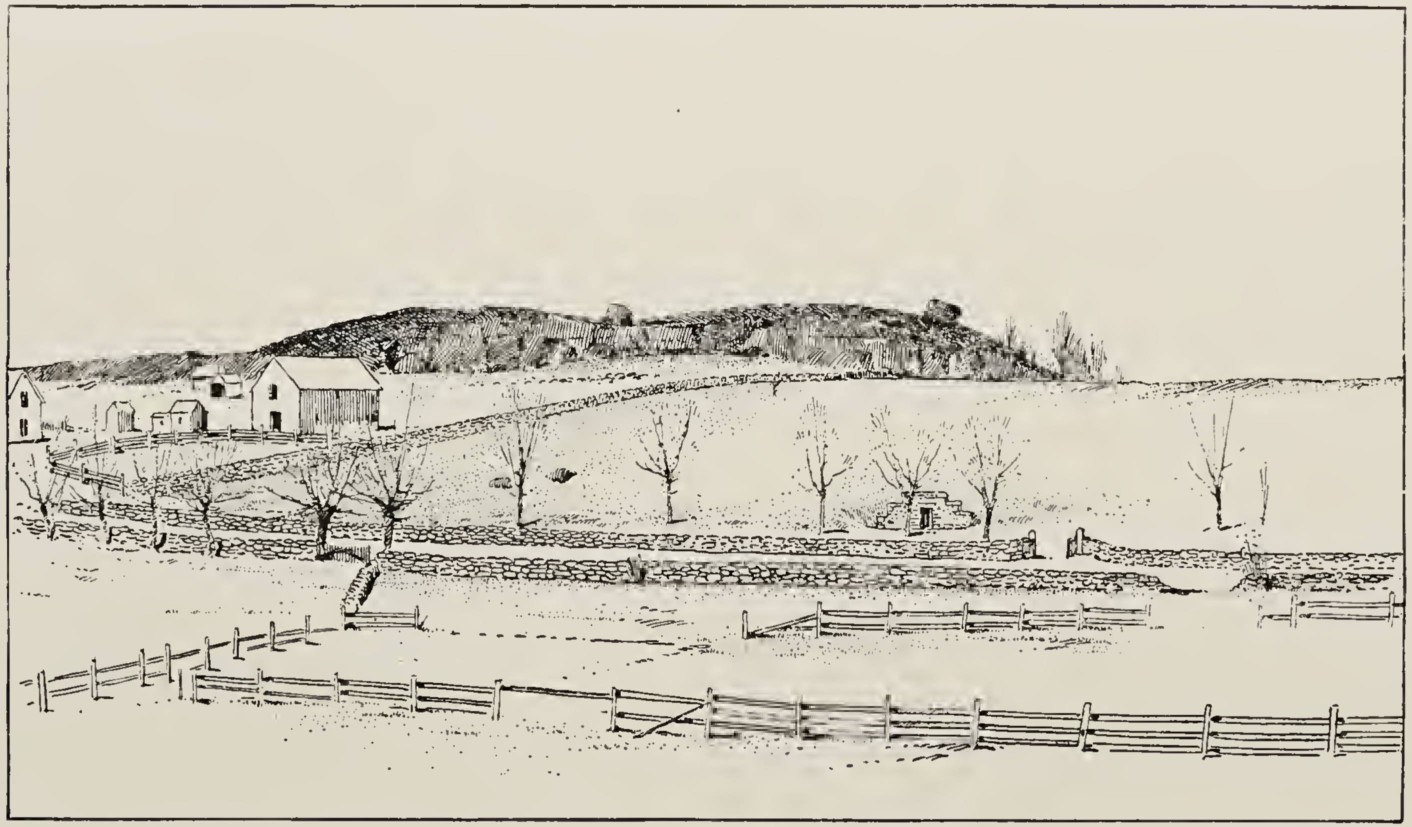
The marshes of Cape Ann occupy but a limited area. They are divisible into three groups, fresh water deposits of the uplands, fresh water deposits formed behind walled beaches, and true tidal marshes. The upland morasses are all of small area and with the

exception of a few deposits made in kame pits they lie altogether in irregularities of the ground or frontal moraines or in the numerous rock basins which beset the surface of the island. None of these areas appear to be drainable and they are therefore of no economic importance. The marshes impounded by beach walls are also of small extent, only one being of sufficient area for discussion. These lie on the shore between Briar's Neck and Bass Rocks. There is here an area of one hundred acres or more, the drainage of which is affected by the access of the tide and a portion of the field is ordinary salt marsh. By closing out the salt water by dams, with considerable exits for the inland waters, an important area can be reclaimed at this point. On Squam River, a considerable fiord which separates the island of Cape Ann from the main, there is a total area of about one hundred acres of reclaimable salt marsh. Unfortunately, a large part of this area is of a sandy nature. The sands which have worked down the shore from the northwest and which have formed in part the dunes of Coffin's Beach have poured into this basin and affected the character of the marshes as far south as Pearce's Island. Nevertheless, these marshes appear to me to be worth winning to agriculture. They can be reclaimed by very slight dams, for the reason that the waves they would face are of trifling size. Although the sand which has been contributed to these marshes will somewhat diminish their fertility, the admixture will make it easier for them to be reduced to the tillage state. Including the marshes along Little River, it appears to me likely that from 300 to 600 acres of high grade agricultural land can be won along the shores of this fiord.

## PHYSICAL STRUCTURE OF THE BED ROCKS OF CAPE ANN.

One of the principal objects of this memoir is to set forth certain features connected with the crystalline rocks of Cape Ann. Nowhere along our coast are rocks of this description so well shown as here. With slight exceptions, where these materials are covered by recently formed beaches, the whole periphery of the island is exposed to view. These rocks form the root of a considerable anticline, the axis of which extends from northeast to southwest. The shore line of Cape Ann affords us by its varied outline extensive sections parallel with the trend of the anticline and across its axis. We are thus enabled to observe in a large way the nature of the accidents which took place during the movement which attended the formation of this mountain ridge.

This region is very favorably suited for the study of joint systems developed in the macro-crystalline rocks, and also for observations on a variety of dike injections which occurred at successive periods during the construction of the mountain uplift. At no other point on the east coast of the United States do we have anything like as good an opportunity to follow the dynamic history of the lower por-



PERCHED BOWLDER RESTING ON BARE GRANITE, ONE-HALF MILE NORTHWEST OF GLOUCESTER STATION; TAKEN FROM A POINT NEAR THE MAIN ROAD TO ANNISQUAM.

tion of an extensive anticline. In the interior districts of the country there are many points at which erosion has in a measure disclosed the substructure of great mountain arches; but so far as is known to me there is no case in which this structure is not very much masked by accumulations of soil or rubbly material. At this point the action of the sea has given us a remarkably clear horizontal section many miles in extent.

The disclosure of this anticline which the sea has afforded extends somewhat beyond the limits of Cape Ann. It begins on the southwest at Lynn and extends along the shore through Swampscott, Marblehead, Beverly, Manchester, and Magnolia, to Cape Ann. Although it is intersected at Cape Ann by the fiord indentation of Annisquam Reach, it is essentially a part of the same geologic structure. It will therefore be necessary to extend our consideration to the shore of Massachusetts Bay as far west as Lynn. It will be particularly desirable to effect this extension for the reason that in the section southwest of Cape Ann we have the peripheral deposits of the anticline fairly well disclosed, and can see the relations of the granitites to the superjacent deposits, which belong in the anticlinal fold or lie upon the node between the up curve and down curve of the mountain arch.

West of Lynn, in the region near the southwestern extremity of Boston Bay syncline, we have an extensive series of more or less metamorphosed rocks, including the Cambridge slates, the Roxbury conglomerates, the Nahant schists, and the Braintree fossiliferous slates. These beds have an aggregate thickness of not less than 6,000 feet, and they may be of much greater depth. They occupy the whole field of the central part of the syncline. In this section there have been very extensive though irregular extrusions of volcanic rocks, rocks which appear to have been in part at least the product of subaerial volcanic action. These deposits are found in the northern part of the syncline near Lynn, Saugus, and Malden. On the south shore they occur in Hingham and Nantasket. They apparently lie in immediate contact with the granitic series which compose the mass of the anticline, and were probably formed after these highly crystalline rocks took on their character and assumed their present relations to the mountain arch.

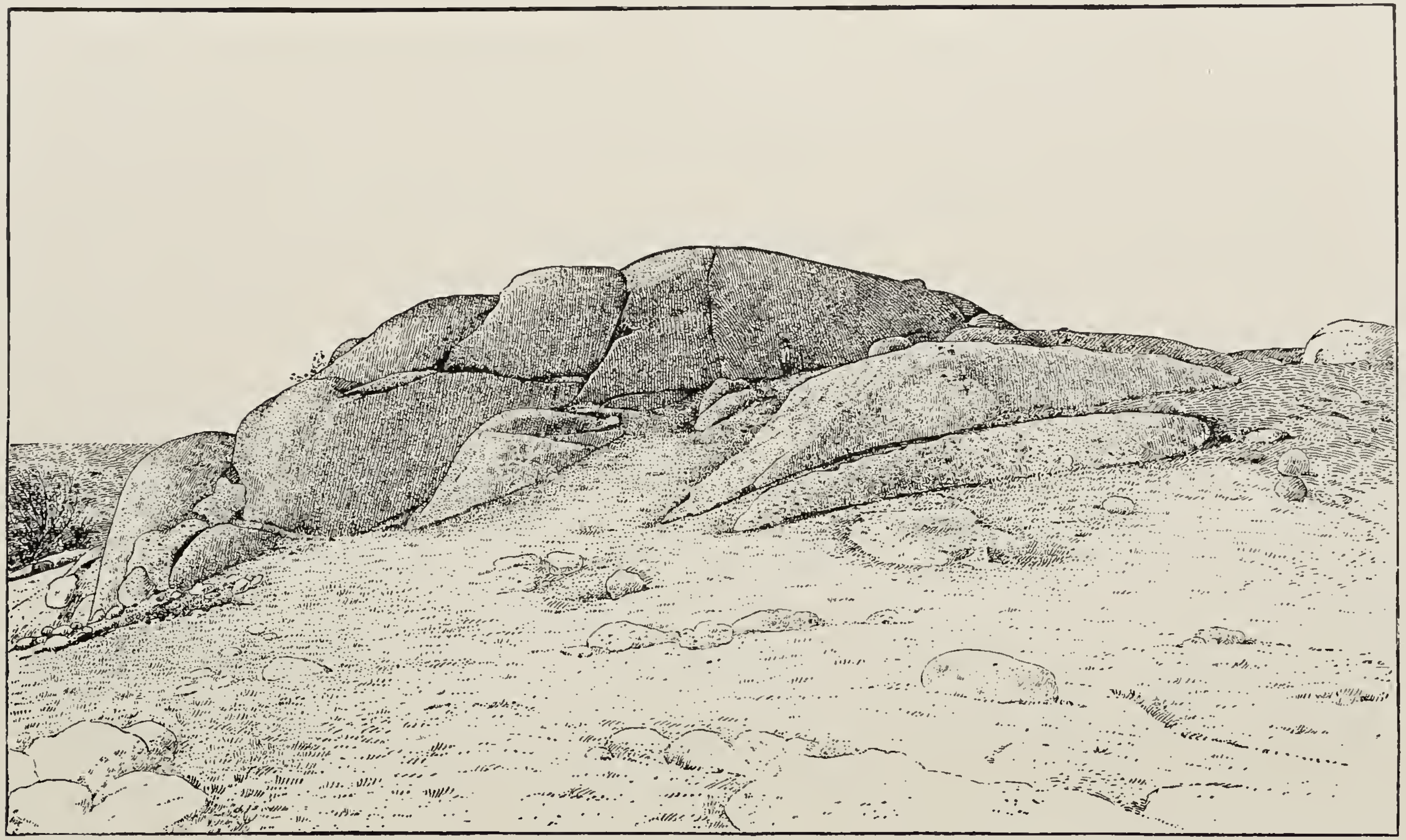
There can be little doubt that a large part of the beds which occupy the central portion of the syncline was deposited before the uplift of the anticlinal axis. The Braintree series appears to have been formed in deep water at a distance from the shore. The slates of Cambridge and Somerville which probably lie at the base of the Roxbury conglomerate also seem to have formed in deep water; but the Roxbury conglomerate contains abundant fragments among its pebbles which appear to have been derived from the erosion of the anticlines which bound the basin in which it lies. Not only are the

granitites and their accompanying dikes of this anticlinal axis extensively represented, composing, indeed, in places a large part of the fragmental material, but the volcanic ejections before mentioned are also represented in these pebbles. It is also probable that a large part, if not the whole, of the Nahant series was deposited after the time when the syncline and the corresponding anticlines on the north and south had begun to develop.

Thus the general history of these mountain movements appears to have been as follows: Anterior to the orographic development of this district, it was occupied by an extensive series of deposits of unknown thickness and of early Cambrian age. Evidence which can not be given here appears to indicate that these ancient beds were considerably eroded before they were disturbed by mountain foldings; then came the formation of the anticlines, attended or followed by the volcanic outbreaks indicated by the remaining accumulations of this nature in Lynn and Nantasket districts. Afterwards, most likely in the period of the Potsdam sandstone, though perhaps at a subsequent date, came the extensive erosions from the anticlines and depositions in the syncline, which produced the Roxbury conglomerates.

This much of the history of the Boston axes is indicated by the beds which lie to the southwest of Swampscott. To the northeast of Swampscott, marine and other erosion has swept away or reduced below the ocean level all the beds which belong in the synclinal as well as those volcanic ejections which lie upon the flanks of the anticlinal, and thence outwardly to the extremity of Cape Ann we have only the roots of the old mountain axis which we are considering. From Lynn eastward the superficial deposits are almost entirely removed and exhibit the succession of crystalline rocks. At first on the west these are more or less gneissoid, and as we go east as far as Beverly they become more and more massive until we find the materials of the normal purely crystalline structure exhibited on Cape Ann. The section from Lynn to Annisquam Reach is in a general way beveled from the higher to the lower and more crystalline rocks. Although it is not possible to trace the section in detail, on account of the abundant faulting and other movements to which it has been subjected, I am inclined to think that there is a belt of gneissoid rocks, having a depth of from 1,000 to 3,000 feet, lying between the purely crystalline granites and the distinctly stratified Cambrian deposits of the syncline. In the main, the volcanic series appears to rest upon and break through these somewhat gneissic rocks.

From Lynn, where the massive crystalline rocks first come to the shore, eastward to Cape Ann, the coast line is abundantly intersected by dikes. Eastward as far as Marblehead, the larger part of these injections consist of distinctly porphyritic material. From Marblehead to Cape Ann, the proportion of this porphyritic material pro-



SUNSET ROCK, ANNISQUAM, MASSACHUSETTS, SHOWING HARD MASS ROUNDED BY GLACIATION AND STRIPPED OF ITS DEBRIS BY MARINE ACTION.

gressively diminishes and the dikes have an ordinary crystalline character becoming relatively more abundant. Along this part of the south wall of the anticline, in which the obscurely gneissic rocks find a place, the dikes are greatly disrupted. Thus, at the Preston House, near the line between the towns of Lynn and Swampscott, where there is a very extensive exposure of massive rocks that have been laid bare by the action of the sea, we find all the dikes extraordinarily ruptured by faults, and broken up in a degree never seen on Cape Ann. In general, it appears that the flanks of this anticline, in the section where the uplift of the anticline is turning to the downward flexure of the syncline, have been much more affected by disruptive movements than the central portions of the anticlinal axis which alone are represented on Cape Ann.

### MINERALOGICAL CHARACTER OF ROCKS.

Within the limits of Cape Ann, saving in the case of small inclusions, all the granitic rock is of an entirely massive character. No trace of gneissoid structure has been observed in any part of that field, the fact probably being that the whole of the gneissic part of the section has been stripped away. Prolonging in a general manner the axis of such rocks as they appear on the southwest, it is readily seen that they come within a mile of the southern portion of this Cape.

Although the granites of Cape Ann vary somewhat in character in different parts of that field, at no point are the variations so far constant that any discrimination of the deposits into distinct areas, at least in the present state of our information, can be effected.

### DIKES OF THE CAPE ANN DISTRICT.

One of the aims of this inquiry has been to determine the number, character, and position of dike intrusions in this district. The study of the shore line where the rocks are bared by the sea, in quarries and other artificial cuttings, has shown a total of 361 dike intrusions. Some 30 dikes which have been observed only in quarries may be identical with some which appear on the coast line, but the repetitions are not likely to diminish the total as set forth above.

The portion of the crystalline rocks of Cape Ann which is bared by the action of the sea or by artificial openings probably does not exceed a twentieth of its total area. Although there are large surfaces of bed rocks exposed to view in the interior of the island, these areas in their natural state reveal few dikes, owing to the fact that the contents of these fissures readily decay and form crevices which are filled with rubble or drift materials. Only five dikes have been determined in these natural exposures of bed rocks, though many have been suspected to exist. The distribution of dikes on the shore, the abundant waste of such injections in the drift, and the

other evidence before adduced go to show that these injections are about as numerous in the interior as they are on the coast. We may therefore reckon that the number of these intrusions within the limits of the island amounts to a much larger number than those exposed to view.

Neglecting at present the topographical character of the dikes, we find the general distribution of such fissures about as follows: Beginning with Eastern Point, we find that promontory moderately intersected with dikes to High Pebble Beach; from that point to Good Harbor Beach the number of these injections rapidly increases. At Bass Rocks they are about as abundant as at any point on the island, constituting perhaps a twenty-fifth of the visible mass. (See Pl. LIX.) They are also extremely abundant on Rocky Neck, in Gloucester harbor. From Bass Rocks to Cape Hedge the shore line is mainly occupied by beach accumulations. On the exposed portion of the shore occupied by Briar Neck inside of Salt Island the dikes are again extremely abundant. The indications derived from the interior appear to make it likely that the rocks to the west of Briar Neck are extensively cut by these injections, which mostly have a northwest and southwest extension. From Cape Hedge to Sandy Bay the number in a given extent of shore line diminishes; they are still, however, tolerably abundant. From Sandy Bay to Folly Cove they are substantially wanting, except in a small extent of shore on Halibut Point, where half a dozen occur. From Folly Cove southwestward they again become abundant and continue so to the mouth of Annisquam harbor, being most developed from Davis's Neck to the entrance of that harbor. Along the shore of Annisquam Reach from its northern mouth to Gloucester the conditions of the shore are not well suited to disclose these dikes, but the evidence seems to indicate that they abound in this portion of the section.

### DISTRIBUTION OF DIKES.

The diagrammatic summaries showing the distribution of dikes give with close approximation to accuracy their distribution as regards compass directions. (Fig. 46.) It will be seen that of the 361 dikes the courses of which have been observed, including about all which are visible on the island, 266 lie in the quadrant between northwest and north, and 150 in the 25° between N. 45° W. and N. 20° W. It is thus evident that by far the greater part of the dikes, 266 out of 361, as against 95 in other parts of the circle, lie in the northwest quadrant, and more than half the total in the 45 degrees between north and northwest. The remainder of the dikes are irregularly distributed, the only considerable accumulation being in the portion of the circle between N. 30° E. and N. 60° E., where there are 44 dikes. The most remarkable concentration is that which occurs between N. 30° and N. 35° W., where in all there are 53 fis-

EAST SIDE OF GLOUCESTER HARBOR, SOUTHEAST FROM TEN-POUND ISLAND, SHOWING DIKE EXCAVATED BY SEA WHEN SHORE WAS ABOUT 10 FEET BELOW PRESENT LEVEL.

sures, or about a seventh of the total number. Thus the ratio of accumulation in these five degrees of the half circle is about as 7 to 36 in the remaining 175 degrees. As a whole the observed attitudes of these dikes show that they are far more developed in the quadrant from north to west than in the quadrant from north to east, in the ratio of 166 to 95, with, as before remarked, a singular concentration in the section between N. 30° W. and N. 35° W.

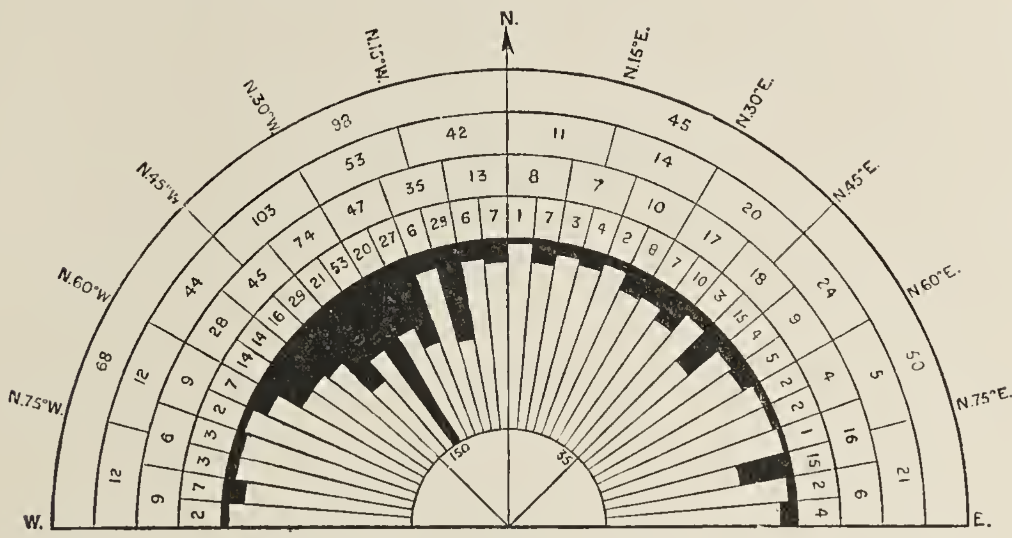



FIG. 45. Diagrammatic tabulation of strikes of dikes on the island of Cape Ann.

The appended diagram (Fig. 47) indicates the attitude of the dikes with reference to the vertical. It shows that the range in position is from 30° to 90°, with a steadfastly increasing number as we approach the vertical position. No dikes of any description have been seen in positions near a horizontal plane. No trace of anything like an approach to a laccolitic structure has been observed in any part of this field.

This enumeration does not include the large masses of diorite in the valley of the Annisquam Fiord nor the great masses of granite porphyry which lie in the same region and on the east shore of Cape Ann.

The range in diameter of the dikes is from a width of forty feet to very narrow intrusions with a width of half an inch, fine stringers often being not more than one-tenth of an inch in diameter at twenty feet from the main mass.

Owing to the conditions of exposure it has not proved possible to trace the horizontal extension of these injections. It is worthy of note, however, that in no case has it proved possible to find both ends of any injection, and in less than half a dozen cases has either extremity been seen. Considering the large number of dikes examined and the fact that many of them have been traced for hundreds of feet, it becomes clear that the longitudinal extension of these fissures is generally great. In the case of one dike, the great porphyritic intrusion of Pigeon Cove, there can be no question that it ex-

tends from a position one-fourth of a mile southwest of Straitsmouth Point, beneath Sandy Bay, to Pigeon Cove, and thence across the island to near Folly Cove. It is true that a portion of this extent is hidden by the sea, but such is the similarity in the physical charac-

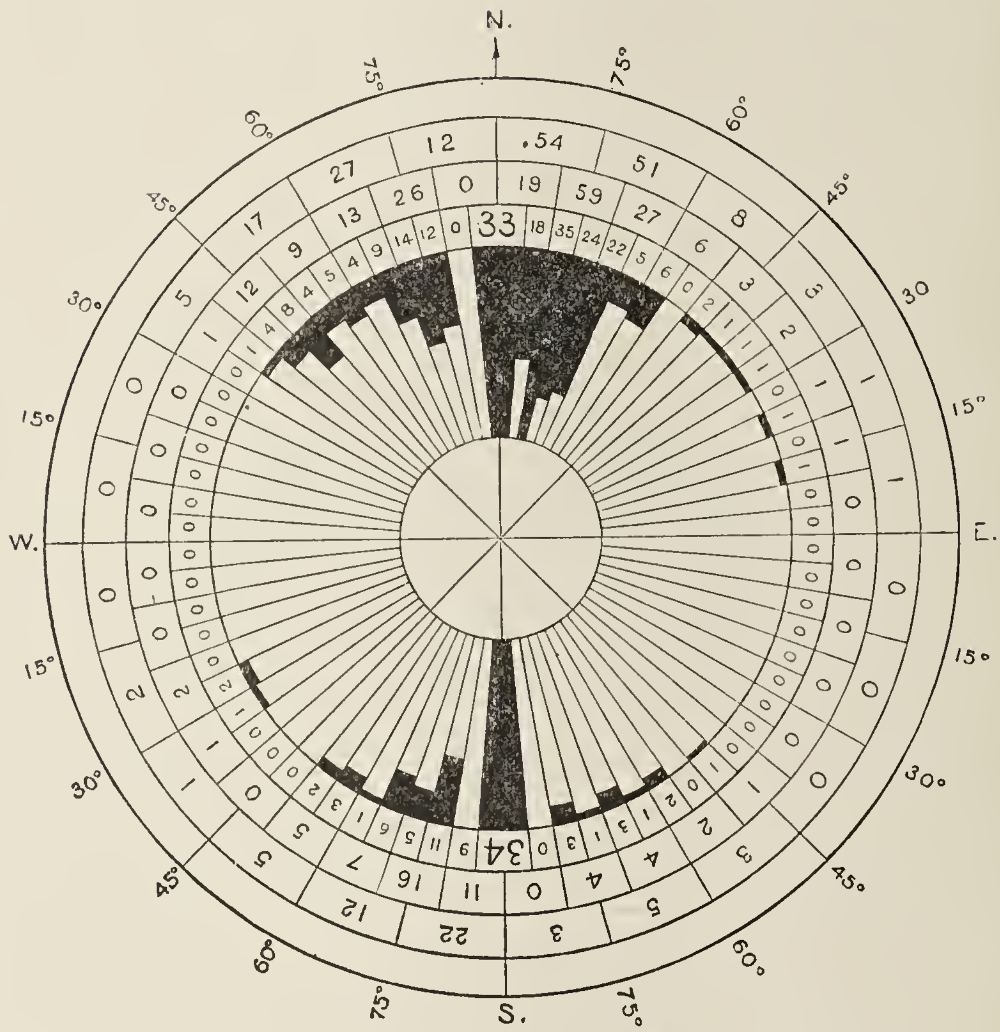
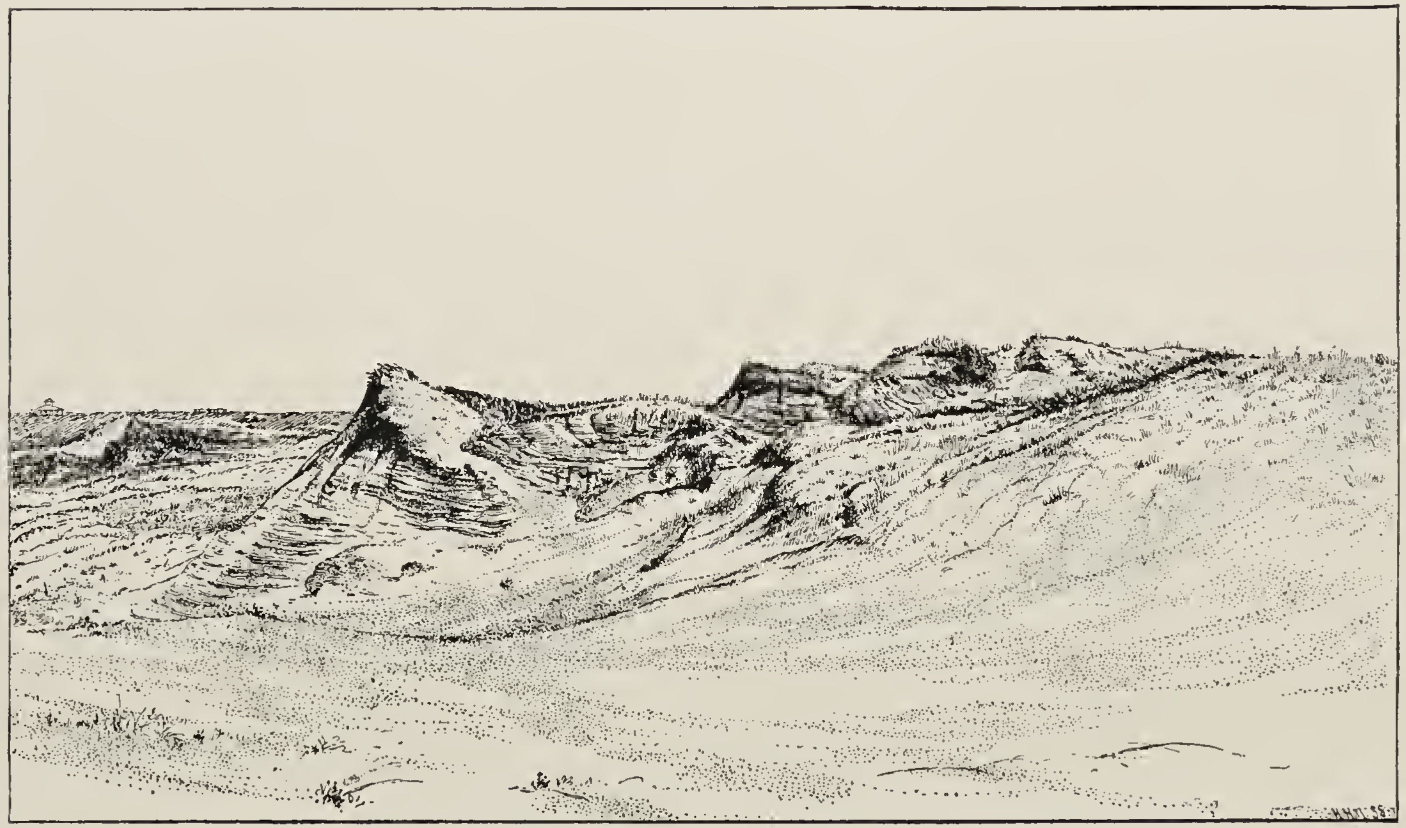



FIG. 46. Tabulation of dips of dikes on the island of Cape Ann.

ter, general strike, and other features of the injection, that the identity of the dike throughout its length can hardly be doubted. The distance between these two points is about three miles.

These dikes in great part are characterized by clean walls, and as a whole they are not greatly cross-faulted, that is, the sides of the fissures are on the whole parallel, and there are few offsets. (See Pls. LXIV, LXV.) A certain group of quartz-porphyry dikes hereafter to be considered in detail have generally very irregular walls. In this case, however, there is no distinct indication of melting of the bounding walls, so that we can not perhaps regard the dikes as volcanic pipes, but must rather attribute the irregularity of their boundaries to some peculiar violence in the outbreak which produced them, or it may be that these ruptures were formed before the development of the joint planes. This latter conjecture is favored by the fact that these quartz porphyries are clearly the



SAND DUNES OF COFFIN'S BEACH.

oldest dikes in this section. Moreover, they are in a given field more faulted than the other dike systems, and therefore are shown to be of earlier age.

The faulting which has affected the district is principally indicated in the earliest set of dikes, viz., the quartz porphyries just mentioned. It is very slightly manifested in the case of the other fissures, and is indicated only at the points of intersection of different sets of dikes. It thus appears that the disruptive forces which produced the faulting did not, to any considerable extent, operate in this field after the work of intrusion was completed.

### AREA OCCUPIED BY DIKES.

At this point we may notice an interesting theoretical consideration dependent upon the number of dikes in this region and the area which they occupy. Basing a computation, first, on a careful eye-estimate of the dike surfaces at different points, and, secondly, on an estimate of the number and diameter of the dikes, it appears pretty certain that on the surface of Cape Ann 5 to 10 per cent. of the superficial area is occupied by such materials. In other words, the horizontal extension of the granites has been increased by somewhere between one-tenth and one-twentieth of the original surface. Besides this increase, due to the injection of materials derived from below, the rocks have received a certain small though incomputable accession from vein materials, principally composed of quartz. In other districts this vein element is an important feature in the extension of the area. On Cape Ann it is so small that we may neglect it.

No particular order in the distribution of these veins has been observed. They are eminently abundant on Eastern Point, near Annisquam, and in the quarries about Rockport; they are rare elsewhere. They seldom exceed two or three inches in diameter and are generally of no considerable length. They do not appear to be connected with the faults, and are, therefore, probably in their nature secretions from the granitic mass formed during the cooling process.

I have elsewhere called attention to the fact that the injection of dike and vein stones would lead perhaps in part at least to movements of the strata which have resulted in the formation of anticlinal axes. It is interesting in this connection to note that a considerable extension of these basement deposits of the Gloucester anticline has taken place.

### JOINT PLANES OF CAPE ANN DISTRICT.

The joint planes of the Cape Ann District as will be seen from the appended tables have been subjected to a careful study. I am not aware that in any preceding memoir involving a similarly extensive district the observations have been presented in an equally elaborate

manner. The observations on these joint planes were made by a compass with a needle having a length of four inches, the circle graduated to degrees with a vernier attachment. In the course of the work, it quickly became evident that it was not possible on account of the decay of the rocks to observe joint phenomena in natural exposures with sufficient accuracy to obtain valuable results. The tabulated work, therefore, has been limited to quarries. It hap-

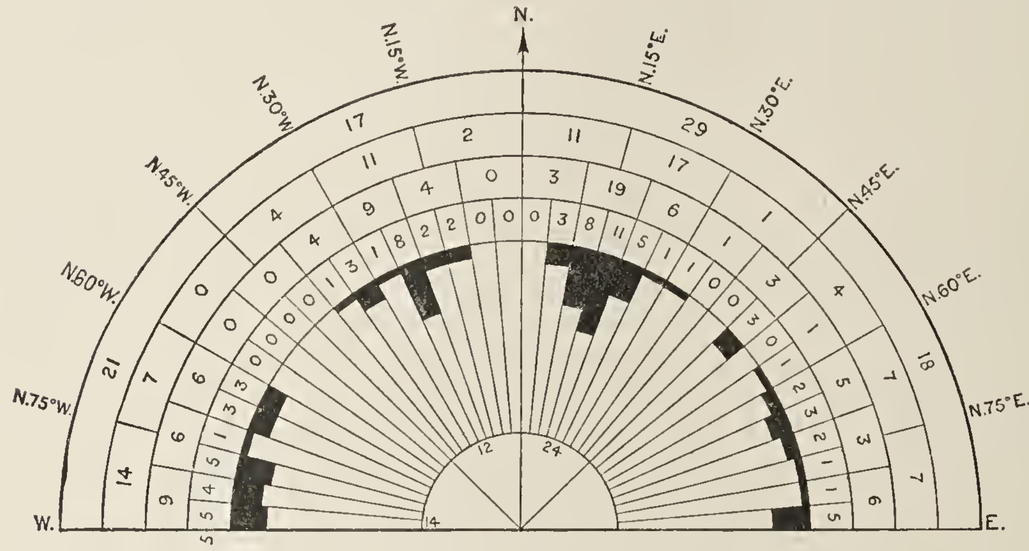



FIG. 47. Tabulation of joint planes in Bay View quarries.

pens, however, that these artificial openings are so far distributed over the area of the island that they fairly represent the joint systems of the whole district. (See Figs. 48 and 49.) Inasmuch, however, as the general phenomena of joints along the coast are of great importance in determining the action of erosive forces, the detailed study of

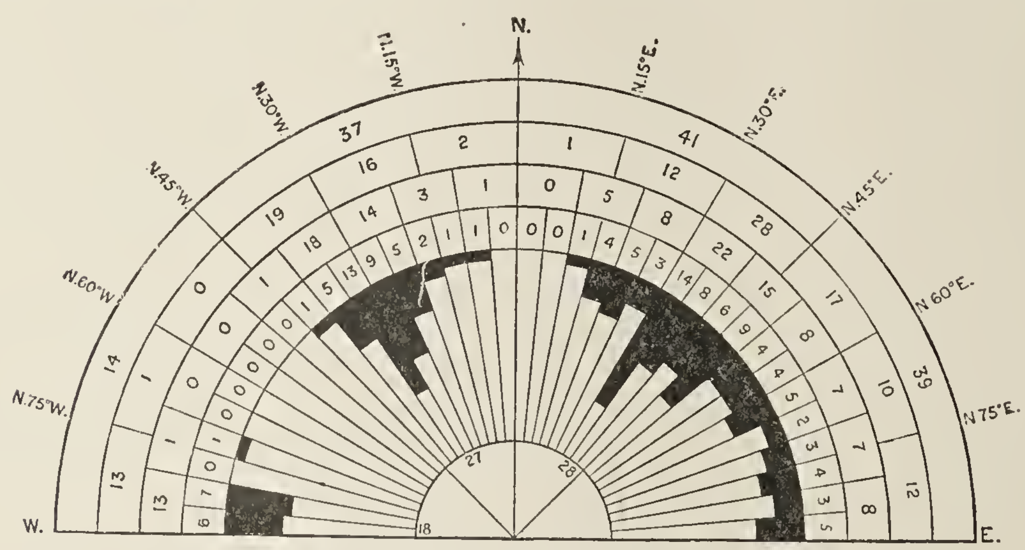
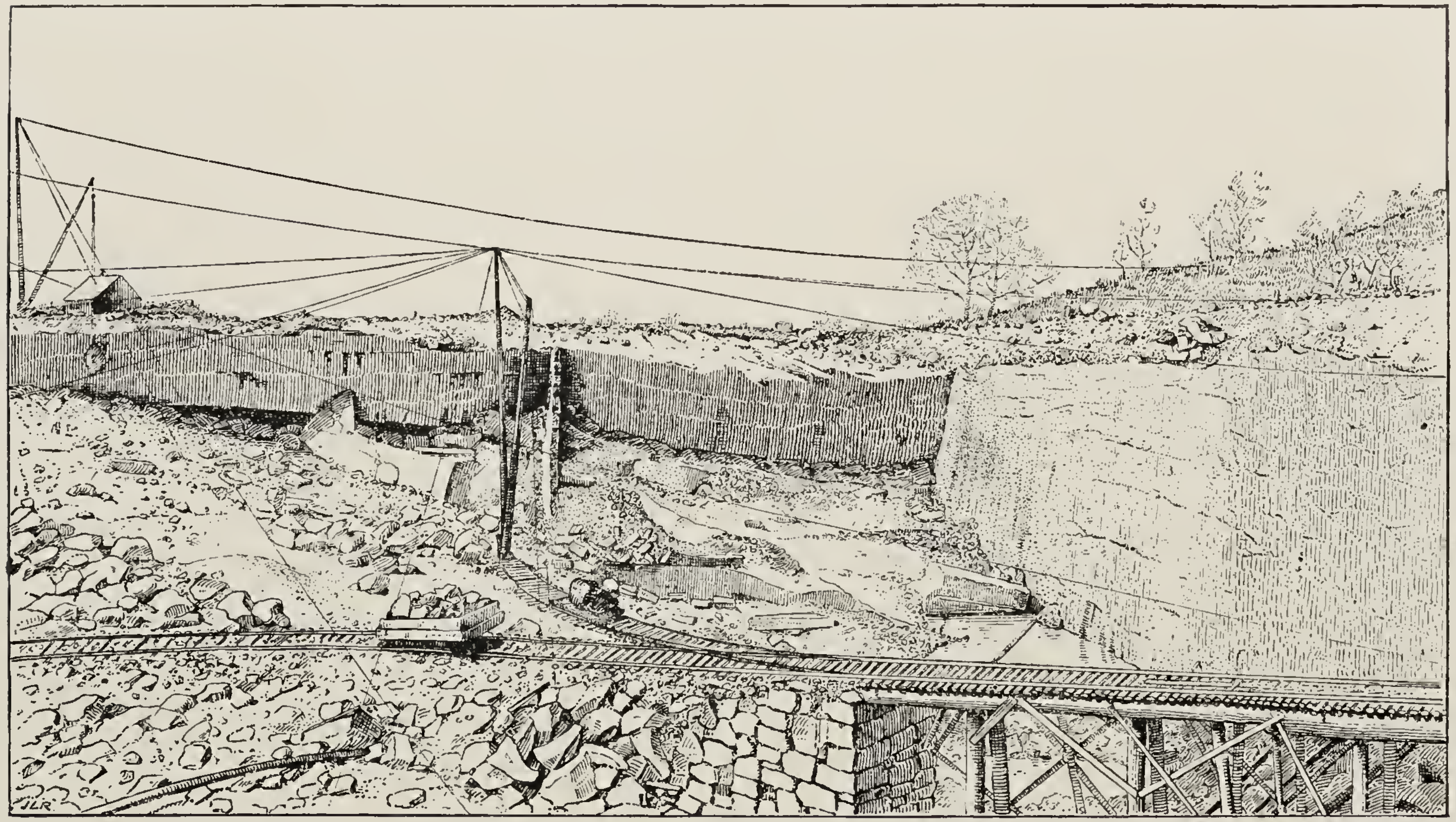



FIG. 48. Diagrammatic illustration of distribution of joint planes in Lanesville quarries.

joint planes will be preceded by a general statement of their character on different parts of the coast, beginning as in the case of dikes with Eastern Point. Eastern Point as far as Brace's Cove exhibits much jointing, the principal fractures having an axis of N. 48° to N.



PIGEON HILL QUARRY, UPPER PIT, SHOWING EXTREME DEVELOPMENT OF HORIZONTAL JOINTING.

53 ° E., dipping nearly vertically, a distance of eight feet apart, varying from one inch to 20 feet, and averaging three or four feet. There are other joints in the same region which can not clearly be referred to any system. Owing to the high angles of the principal joints, the weather and ice have not much affected the rocks in this portion of the section, and as a consequence it is one of the boldest portions of the shore of the island. In the vicinity of Brace's Cove the joint planes are close together, averaging less than a foot apart, and inclining in various directions, so that the rock splits in small fragments of little more than one-fiftieth of a cubic foot. It is probably to this morcellated character of the rock given by the joints that we owe the great erosion of the granites which has formed the low land in which lie Brace's Cove, Niles's Pond and the other depressions of this vicinity.

From Brace's Cove to Bass Rocks the manifest joint systems are fewer in number and the places farther apart. With this diminution in jointing, the shore again assumes a bold character. At Bass Rocks the joint structure is very imperfectly developed (Pl. LIX), the rocks being here perhas more massive than at any other point on the periphery of the island, although the dike injections are more numerous here than elsewhere. From Bass Rocks to Cape Hedge the joints are again more numerous, and to this greater development may perhaps be due the recession of the shore on this part of the island. At certain points the jointing in the measure of its development approaches the conditions shown at Brace's Cove. From Cape Hedge to Straitsmouth Point, there are but two distinct vertical systems of joints which are evident, viz, those running N. 48° W. and those running N. 32° E., together with a horizontal set, the three serving to detach numerous very massive fragments. At several points on this portion of the coast are small patches of granite which are almost as much jointed as the large field of such material at Brace's Cove. Wherever these patches occur the effect of marine erosion is at once evident. The coast line is beaten back until in process of retreat it obtains a certain protection from the assault of waves from detritus which lodges in the re-entrant angle. Going north from Eastern Point this is the first portion of the shore on which the horizontal jointing distinctly appears.

On the south shore of Sandy Bay, between Straitsmouth Point and the village, the vertical jointing runs N. 3° W. and N. 52° E. At this point the distinct horizontal joint planes become less marked and are replaced by a number of divergent planes. From Sandy Bay along the shore to Folly Cove, we have the conditions of jointing which are shown in detail in the Pigeon Cove quarries. (See Pls. LXVI, LXVII, LXVIII, LXIX, LXX, LXXI.) The planes strike N. 78° W. with a dip to the NE. of 55°. Another set of nearly horizontal shelving somewhat irregular joint planes strikes in a general

way east and west, dipping to the south at an angle of 10° or 12°. Yet another set strikes N. 43° E. with a vertical dip. These three joints lead to the formation of rhomboidal fragments which are frequently as much as 4 feet wide, 12 feet long and varying from 1 to 4 feet in thickness. The size of these fragments shows that the joint planes are far apart. The attitude of the planes towards each other and their

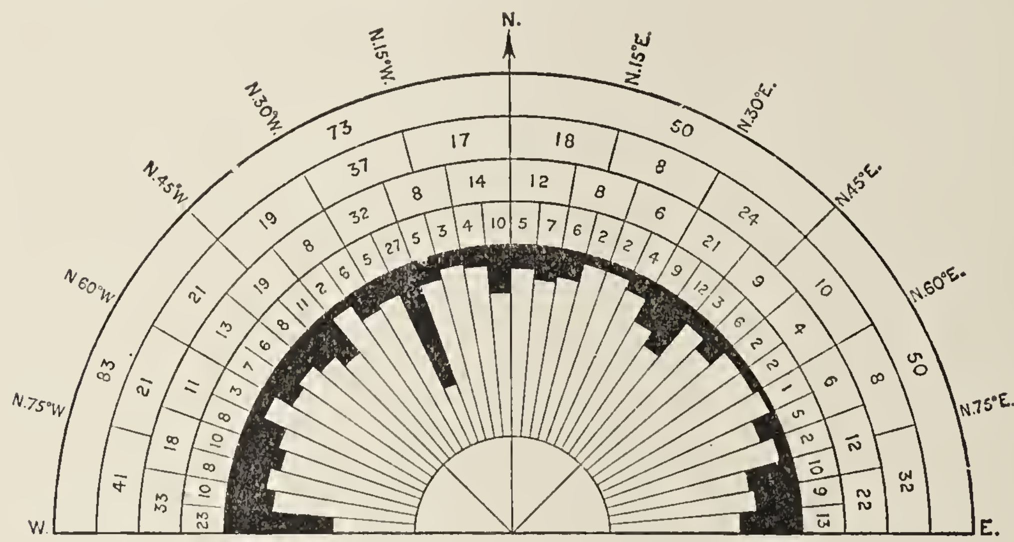



Fig. 49. Tabulation of joints in Rockport quarries.

position in relation to marine erosion has doubtless served to protect this part of the island from glacial and other wearing, and has thus led to the preservation of the great salient which terminates in Halibut Point. So, too, the generally level character of this area and the gradual slope with which it meets the sea may be accounted for by

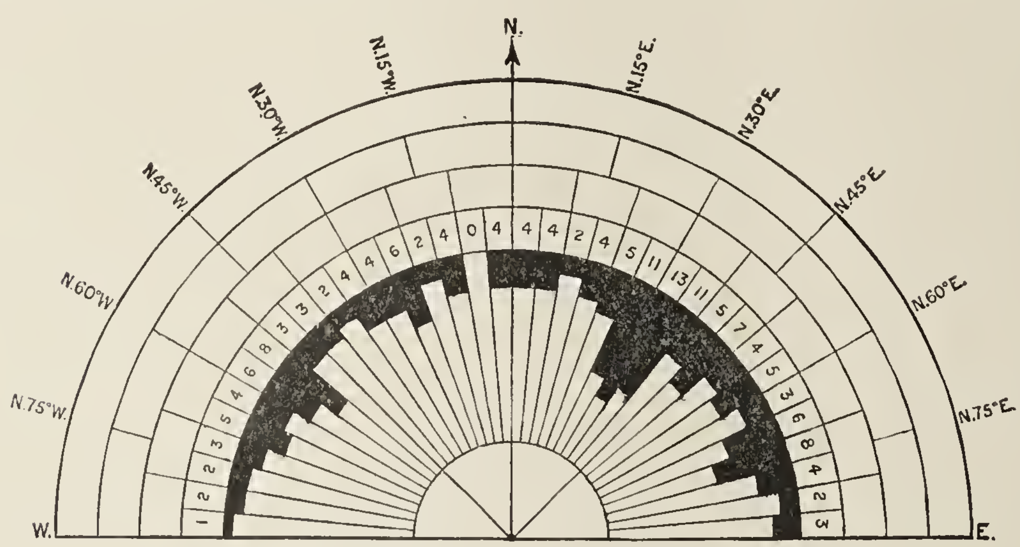



Fig. 50. Tabulation of joint planes in Pigeon Cove quarries.

the attitude of the joint systems. The joints of this section, particularly those which strike N. 43° E., are remarkable for the continuity of the individual planes. In some cases they may be observed extending on the shore line for the distance of 300 feet or more.


BASALTIC JOINTING IN DIKE AT STONE BRIDGE ONE-QUARTER OF A MILE EAST OF GLOUCESTER.

The rock is less cut by joint planes and therefore more massive in the region about Andrews Point. At Halibut Point, the strong northeast waves have disrupted a large quantity of material which serves in a measure to protect the shore from the further assault of the waves. The vigor of the wave action is shown by the size of the fragments thrown up far beyond the ordinary range of the sea. Between Halibut Point and Folly Cove is a section of rock which has been subjected to interstitial decay and exposes the joint planes imperfectly. The depression of Folly Cove and the trough which extends southward for a mile or more from its head is perhaps caused by a lack of resistance in the material. Folly Point is characterized by a considerable immunity from jointing. These joints are at this point so irregular that it does not seem possible to reduce them to definite sets.

A moderate immunity from joints characterizes the whole shore from Folly Cove to Annisquam, and here also it has not proved possible to reduce the joint planes to a definite order.

The shores of Annisquam Reach exhibit a system of very closely juxtaposed joints which so divide the rock that it normally breaks up into fragments not exceeding about ten cubic inches in contents. It is perhaps to the ample jointing of this section that we owe the deep and continuous depression in which lies this system of fiord of Annisquam River. (See diagrams of jointing in quarries, Figs. 50, 51, 52, and Pls. LXXII, LXXIII, LXXIV.)

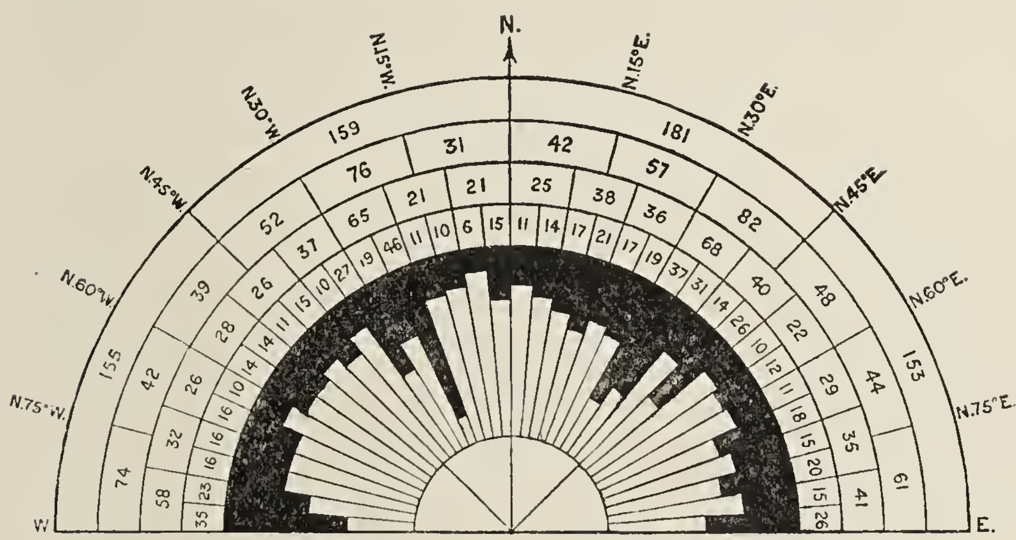



FIG. 51. General tabulation of joint planes.

The foregoing survey of the shore from the point of view of joint planes, makes it tolerably evident that there is some relation between the salients and re-entrants of the coast line and the jointed character of the rocks. A study of the field would show the student that this is the case more effectively than it is indicated to him by the necessarily cursory account which we have given him. In fact,

the measure of resistance both to marine and glacial action, the two modes of erosive energy which have in the main shaped this region, is in good part determined by the attitude of the joint planes. The preceding pages afford a basis for this general description as far as the sea shore and wave action are concerned. Evidence of a similar sort may readily be found to show the influence of the joint planes on glacial wear. Thus whenever the granitic rocks form sharp projections in the interior district, we always find these salients to be composed of little jointed material, while in the depressions a variety of evidence freely leads to the inference that they are occupied by rocks more closely intersected by these rupture planes.

Turning now to the conditions in the several quarries, we note the following facts concerning joints in different parts of the field which have been bared by quarrying work. Fig. 50 exhibits the attitude of the joint planes in the Rockport system. It will be seen by the diagram that the joints having their planes in the northwest quadrant amount to 156, while those in the northeast quadrant amount to but 100; those in the north-northwest octant to 73, while those in the northwest-by-west octant amount to 83. Thus, as in the case of the dikes, though in a less degree, there is in this particular part of the field an accumulation of joints in the northwest quadrant.

In the Pigeon Cove quarries (see Fig. 51) the conditions are reversed. There are 53 joint planes in the northwest quadrant and 101 in the northeast quadrant. In the Lanesville quarries the conditions are like those at Pigeon Cove, with a proportionately greater number in the northeast quadrant, the numbers being 51 in the northwest quadrant and 80 in the northeast quadrant. In the Bay View quarries, there is very little difference between the number of joints in the two quarries, there being 38 in that of the northwest and 47 in the northeast quadrant.

Thus it appears as the result of sufficiently numerous observations of the joint planes and their associated dikes that while the dikes distinctly follow joint planes there does not appear to be any such relation between them as would enable us to say that the number of dikes was in any measure determined by the number of incipient fissures afforded by the joints, or, in other words, the conditions which guided the direction of the dikes were probably due to some feature or condition not inherent in the joints themselves.

ROCKPORT GRANITE COMPANY'S QUARRY, SHOWING ABSENCE OF VERTICAL JOINTS AND CHANGE IN CHARACTER OF PLANES IN THE DEEPER PARTS OF THE SECTION.

## LIST OF DIKES OF CAPE ANN.

[The numbers in the following list refer to corresponding numbers upon the map of the bed rocks of Cape Ann. The identification of the dike rocks has been mainly from hand specimens and necessarily no attempt has been made to classify them upon strictly petrographical grounds.]

| No. on map. | Strike. | Dip. | Width. | Name. | General remarks. |
|---|---|---|---|---|---|
| 1 | N. 17° E. | 85° W | 2½ feet | Diabase | An irregular dike. |
| 2 | N. 77° E. | 75° N | 2 feet | Porphyritic diabase | Somewhat faulted. |
| 3 | N. 2° E. | 70° SE | 10 feet | Quartz porphyry | |
| 4 | N. 72° E. | | 2½ feet | Porphyritic diabase | |
| 5 | N. 12° E. | 60° W. | 12 feet | Diabase | |
| 6 | N. 77° E. | 85° N | 3 feet | | Worn into a deep chasm for considerable distance above high tide. |
| 7 | N. 77° E. | 60° N | 1½ feet | Diabase | |
| 8 | N. 12° E. | 75° W. | 7 feet | Quartz porphyry | |
| 9 | N. 17° E. | 90° | 2½ feet | Porphyritic diabase | An irregular dike. |
| 10 | N. 3° W. | 75° N | 8 feet | Quartz porphyry | |
| 11 | N. 13° W. to N. 22° E. | 75° W. | 11 feet | Diabase | Crystals of feldspar 6 inches long. |
| 12 | N. 27° E. to N. 13° W. | | | do | A chasm. |
| 13 | N. 58° to 81° W. | 90° | 3 to 6 feet. | | |
| 14 | N. 12° E. | | | Feldspar porphyry | |
| 15 | N. 83° W. to N. 57° E. | 90° | 3½ feet | do | A very irregular dike. |
| 16 | N. 21° to 42° E. | 80° N | 3 feet | Diabase | |
| 17 | N. 62° E. | 80° N | 4 feet | Porphyritic diabase | Very irregular. Cuts 16. |
| 18 | N. 53° W | | 8 inches | Diabase | |
| 19 | N. 47° E. | 90° | 3½ feet | do | |
| 20 | N. 67° E. | | 2 feet | do | |
| 21 | N. 32° E. | 90° | 2 feet | | |
| 22 | N. 77° E. | 75° N | 3 feet | Diabase | |
| 23 | N. 62° E. | 50° S. | ½ inch to 4 feet. | Feldspar porphyry | Very irregular and ragged. |
| 24 | N. 42° E. | 60° N | 3½ feet | Diabase | |
| 25 | N. 47° E. | | 8 inches | | |
| 26 | N. 32° E. | 55° N | 3 feet | | |
| 27 | N. 22° to 42° E. | 90° | 2½ feet | Diabase | |
| 28 | N. 57° E. | 75° N | 3½ feet | | |
| 29 | N. 13° W | 80° N | 7 feet | Diabase | A chasm. |
| 30 | N. 87° E. | 80° N | 15 to 18 feet | do | |
| 31 | N. 43° W | 80° SW | 6 feet | | |
| 32 | N. 28° W | 60° E. | 2 feet | Diabase | |
| 33 | N. 33° W | 90° | 1½ feet | | |
| 34 | N. 78° W | 60° W. | 2½ feet | | |
| 35 | N. 83° W | 70° N | 18 feet | Diabase | Irregular. |
| 36 | N. 43° W | 90° | 3½ feet | do | |
| 37 | N. 27° E. | 60° SE | 2 feet | | |
| 38 | N. 25° W | 90° | 1 foot. | Diabase | |
| 39 | N. 38° W | | 6 feet | | |
| 40 | N. 33° W | | 2 feet | | |
| 41 | N. 38° W | 70° SW | 2 feet | Diabase | |
| 42 | N. 63° W | 85° SW | 3 feet | Porphyritic diabase | Very irregular. |
| 43 | N. 27° E. | 60° NW | 4 feet | do | |
| 44 | N. 33° W | 80° SW | 4 feet | | |

*List of dikes of Cape Ann*—Continued.

| No. on map. | Strike. | Dip. | Width. | Name. | General Remarks. |
|---|---|---|---|---|---|
| 45 | N. 13° W | 80° SW | 2 feet | Diabase | |
| 46 | N. 33° W to N. 37° E. | 55° SW | 1 foot | | Very irregular. |
| 47 | N. 42° E | 70° NW | 6 inches | | |
| 48 | N. 13° W | 60° NE | 3 feet | | Rather irregular. |
| 49 | N. 77° E | 70° S | 3 feet | | |
| 50 | N. 43° W | | 6 to 8 inches | | Very irregular. |
| 51 | N. 53° W | 90° | 2½ feet | | |
| 52 | N. 37° E | 70° SW | 5 feet | Feldspar porphyry | |
| 53 | N. 49° W | 90° | 1½ feet | do | |
| 54 | N. 37° E | 70° NW | 4 feet | Diabase | |
| 55 | N. 58° W | 90° | 22 feet | Feldspar porphyry | Cut by 57 and probably by 56. |
| 56 | N. 47° E | 50° NW | 10 feet+ | | |
| 57 | N. 47° E | 75° N | 7 feet | Diabase | |
| 58 | N. 58° W | 70 to 80° NE | 20 feet | | |
| 59 | N. 62° E | 75° W | 3 feet | Diabase | |
| 60 | N. 52° E | 80° N | 2½ feet | do | |
| 61 | N. 49° E | 90° | 4 feet | do | |
| 62 | N. 77° E | 75° N | 4 feet | do | |
| 63 | N. 47° E | 75° N | 3 feet+ | do | |
| 64 | N. 27° E | | | do | A chasm with the dike matter washed out. |
| 65 | N. 58° W | 90° | 3 to 4 feet | do | Very irregular. |
| 66 | N. 1° W | 35° W | 4 inches | do | Disappears. |
| 67 | N. 52° E | 65 to 70° N | 2½ inches | do | |
| 68 | N. 41° W | 90° | 1 foot | do | |
| 69 | N. 38° W | 90° | 4½ feet | do | |
| 70 | N. 77° E | 75° | 6½ feet | Feldspar porphyry | |
| 71 | N. 13° W | 90° | 4 to 5 feet | Diabase | |
| 72 | N. 33° W | 90° | 9 feet | do | |
| 73 | N. 7° E | 90° | | do | 73 cuts 70. |
| 74 | N. 53° W | 83° S | 1½ inches | do | Disappears. |
| 75 | N. 43° W | 75° S | 1½ to 2½ inches. | do | |
| 76 | N. 53° W | 80° S | 3½ feet | do | |
| 77 | N. 59° W | 90° | 3½ feet | do | |
| 78 | N. 33° W | 80° NE | 3½ feet | do | 78 branches forming 78ª. |
| 78ª | N. 18° W | 75° E | 3½ feet | do | |
| 79 | N. 18° to 33° W. | 90° | 4 feet+ | | Dike matter eroded away. |
| 80 | N. 63° W | 90° | 7 feet | Diabase | |
| 81 | N. 33° W | 75° W | | do | |
| 82 | N. 61° W | 90° | 1 foot | do | |
| 83 | N. 35° W | 80° E | 6 feet | | |
| 84 | N. 30° E | 70° N (?) | 10 feet (?) | Diabase (?) | |
| 85 | N. 51° W | | 6 feet+ | Diabase | |
| 86 | N. 49° E | 70° S | 5 inches to 1 foot. | do | |
| 87 | N. 43° W | 80° E | 4 feet | | |
| 88 | N. 49° W | 80°+ | | Diabase | |
| 89 | N. 57° E | 75° S | 2 to 3 feet | do | |
| 90 | N. 23° W | | 6 feet | do | |
| 91 | N. 47° E | | 8 feet | do | |
| 92 | N. 27° E | 45° N | 3½ feet | Feldspar porphyry | |
| 93 | N. 23° W | 80 to 85° E | 3 feet | Diabase | |

DORMAN'S QUARRY, ON SIDE OF MAIN ROAD FROM ROCKPORT TO PIGEON COVE, SHOWING TWO PRINCIPAL SETS OF JOINTS.

*List of dikes of Cape Ann*—Continued.

| No. on map. | Strike. | Dip. | Width. | Name. | General Remarks |
|---|---|---|---|---|---|
| 94 | N. 63° W | 90° | 21 feet | Diabase | |
| 95 | N. 87° E. | 90° | 1½ feet | do | |
| 96 | N. 47° E. | 80° N | 1½ feet | do | |
| 97 | N. 6° E | 80° SE | 1½ feet | | |
| 98 | N. 43° W | | 5 feet | | |
| 99 | N. 53° W | 80° NE | | | Irregular. |
| 100 | N. 47° E. | 75° N | ½ inch | | |
| 100a | N. 17° E. | 75° NW | 1 inch | | |
| 100b | N. 37° E. | 75° N | 2½ inches | | |
| 101 | N. 48° W | | 1 foot | | |
| 102 | N. 37° E. | 75° N | 1½ feet | Diabase | |
| 103 | N. 13° W | 70° E. | 1 foot | | |
| 104 | N. 58° W. | | 15 feet + | Holocrystalline diabase. | |
| 105 | N. 43° W. to N. 57° E. | 70° S. | 6 inches to 1½ feet. | Diabase | Very irregular. |
| 106 | N. 13° W | 70° E. | 1½ feet | do | |
| 107 | N. 37° E. | 90° | 3 feet | do | |
| 108 | N. 9° W | 70° E. | 12 feet | do | |
| 109 | N. 33° W | 82° W. | 3 feet | do | Probably an offshoot of 108. |
| 110 | N. 38° W | 90° | 3 feet | do | |
| 111 | N. 23° W | 90° | 5 to 6 inches | do | |
| 112 | N. 23° W | 75° E. | 4 inches | | |
| 113 | N. 33° W | | 3 feet | Feldspar porphyry | Forked dike. |
| 113a | N. 58° W | 50° NE. | 2½ feet | do | do. |
| 113b | N. 43° W | 65 to 85° NE | 2 feet | do | do. |
| 114 | N. 35° W | 80° E. | 2½ feet | | |
| 115 | N. 23° W | 75° E. | 9 feet | | |
| 116 | N. 33° W | 15° E. | 1 foot | Quartz porphyry | Very irregular. |
| 117 | N. 23° W | 85° E. | 2½ feet | Diabase | |
| 118 | N. 27° E. | 50° NW. | 8 inches | do | do. |
| 119 | N. 17° E. | 45° W. | 1½ feet | do | Forked dike. |
| 119a | N. 17° E. | 45° W. | 1 foot | do | do. |
| 119b | N. 32° E. | 45° W. | 1 foot | do | do. |
| 120 | N. 57° E. | 50° NW | 2 feet | do | Cuts 121. |
| 121 | N. 33° W | 90° | 10 feet | do | Extremely irregular and faulted. |
| 121a | N. 43° W | 90° | 10 feet | do | do. |
| 121b | N. 13° W. | 70° E | 2 feet | do | do. |
| 121c | N. 43° W | 90° | 2 feet | do | do. |
| 122 | N. 38° W. | 60° E. | 1 foot | do | |
| 123 | N. 28° W | 80 to 85° NE | 6½ feet | do | Forked dike. |
| 123a | N. 35° W | 85° NE. | 6½ feet | do | do. |
| 123b | N. 43° W | 80° NE. | 2 feet | do | Offshoot of 123. |
| 124 | N. 33° W | 90° | 9 feet | Porphyritic diabase | |
| 125 | N. 43° W | 90° | 1 foot | | |
| 126 | N. 67° E. | 70° S. | 2 feet | Diabase | |
| 126a | N. 77° E. | 65° S. | 6 inches | do | |
| 126b | N. 73° W | 70° S. | 1 foot | do | |
| 126c | N. 12° E | 60° S | 1 foot | do | |
| 127 | N. 37° E. | 60° N | 10 feet | Quartz porphyry | |
| 128 | | | | do | Very ragged and irregular. |
| 129 | N. 77° E. | | 15 feet | do | Irregular. |
| 130 | N. 18° W | 80° E. | 10 feet | Diabase | |
| 131 | N. 33° W | 80° SE | 2 feet | do | |

*List of dikes of Cape Ann*—Continued.

| No. on map. | Strike. | Dip. | Width. | Name. | General remarks. |
|---|---|---|---|---|---|
| 132 | N. 53° to 63° W. | ........... | 2 feet | Diabase | |
| 133 | N. 47° E. | 40° N | 8 inches | do | |
| 134 | N. 27° to 57° E. | 50° N | 2 feet | do | |
| 135 | N. 47° E. | 65° N | 50 to 60 feet | Quartz porphyry | Very irregular and ragged. |
| 136 | N. 83° W | 45° N | 3½ feet | Diabase | |
| 137 | ........... | ........... | ........... | Quartz porphyry | Ragged and irregular. |
| 138 | N. 21° W | 75° NE | 2 feet | Diabase | Irregular. |
| 139 | N. 3° W | 80° NW | 2 feet | do | |
| 140 | N. 13° W | 76° NW | 3 feet | do | |
| 141 | N. 5° E. to 13° W. | ........... | 8 feet | do | |
| 142 | N. 32° E | ........... | 10 feet + | ........... | |
| 143 | N. 18° W | 90° | 1 foot | ........... | |
| 144 | N. 32° E. | 45° NW | 7 feet | Diabase | |
| 145 | N. 32° to 67° E. | 55° NW | 6 feet | ........... | |
| 146 | N. 67° E | 80° N | ........... | ........... | |
| 147 | N. 53° W | ........... | 2½ feet | Spherulitic quartz porphyry. | |
| 148 | N. 13° W | ........... | 2 feet | ........... | |
| 149 | N. 3° W | 90° | 2 feet | ........... | |
| 150 | N. 83° W | 80° N | 5 feet | Diabase | |
| 151 | N. 48° W | 85° S | 9 feet | do | |
| 152 | N. 47° W | 85° S | 9 feet | do | |
| 153 | N. 52° E. | ........... | 2 feet | do | Irregular. |
| 154 | N. 47° E | 55° N | ........... | do | Cut by 157. |
| 155 | N. 32° E. | 60° N | 6 feet | do | Irregular. |
| 156 | N. 33° W | 90° | 2¼ feet | do | |
| 156a | N. 33° W | 65° E | 1 foot | do | |
| 157 | N. 47° E | 90° | 2 feet | do | |
| 158 | N. 13° W | 90° | 1½ feet | Feldspar porphyry | |
| 159 | N. 23° W | 80° NE | 8 feet | do | Irregular. |
| 160 | N. 47° E | 60° NW | 20 feet + | ........... | |
| 161 | N. 23° W | 80° NE | 7 feet | ........... | |
| 162 | N. 13° W | 90° | 2 feet | Nelaphyric diabase | |
| 163 | N. 31° W | ........... | 10 feet + | Diabase | |
| 164 | N. 30° W | 80° NE | 3½ feet | do | |
| 165 | N. 7° E | 50° W | 4½ feet | do | Irregular. |
| 166 | N. 13° W | 90° | 3 feet | do | |
| 167 | N. 41° W | 75° E | 12½ feet | do | |
| 168 | N. 37° W | 68° SW | 1 foot | do | |
| 169 | N. 25° W | 75° NE | 4 feet | ........... | |
| 170 | N. 13° W | 35° NE | 1½ to 2½ feet | Diabase | |
| 171 | N. 7° E | 50° NE | 1 foot | do | |
| 172 | N. 9° W | 80° NE | 18 feet | do | |
| 173 | N. 23° W | 80° NE | 3 to 3½ feet. | Porphyritic diabase | |
| 174 | N. 32° E | 55° N | 3 feet | Diabase | |
| 175 | N. 21° W | 80° NE | 18 feet | Porphyritic diabase | Same as 172. |
| 176 | N. 37° W | 30° S | 1 foot | Quartz porphyry | |
| 177 | N. 77° E | 75° N | 18 feet | Diabase | |
| 178 | N. 73° E | 75° N | 21 feet | do | |
| 179 | N. 83° W | 70° N | 1 foot 5 inches. | do | |
| 180 | N. 78° W | 80° N | 2¼ feet | do | |
| 181 | N. 87° E | 80° N | 3 inches | do | |
| 182 | N. 73° W | 65° W | 3½ feet | Feldspar porphyry | |


ROCKPORT GRANITE COMPANY'S QUARRY NORTHERN END OF LOWER PIT, SHOWING PROGRESSIVE INFREQUENCY OF JOINTS AT DEPTHS BELOW THE SURFACE.

*List of dikes of Cape Ann*—Continued.

| No. on map. | Strike. | Dip. | Width. | Name. | General remarks. |
|---|---|---|---|---|---|
| 183 | N. 41° W ...... | 70° NE.... | 5 feet..... | Feldspar porphyry ..... | Irregular. |
| 183a | N. 87° E. ...... | 80° NE.... | 3 feet..... | ......do ............... | |
| 184 | N. 43° W . ... | 85° NE.... | 1 foot 5 inches. | ......do ..... .......... | Offshoot of 183. |
| 184a | N. 45° W ...... | ............ | 4 feet..... | ......do ... ............ | |
| 185 | N. 27° E....... | 65° W..... | 3½ feet ... | Diabase .. ............ | |
| 185a | N. 77° E....... | 80° N ..... | 16 feet.... | ......do ..... ... ....... | |
| 186 | N. 7° E ....... | 70° N ..... | 25 to 35 feet | ........................ | |
| 187 | N. 2° E........ | 70 to 80° W. | 3 feet..... | Altered porphyritic diabase. | Chasm. |
| 188 | N. 77° E....... | ............ | 3 feet..... | Diabase ........... .... | |
| 189 | N. 53° W ...... | 75° S...... | 2 feet..... | ........................ | Irregular. |
| 190 | N. 43° W ..... | 80° NE.... | .......... | ........................ | |
| 191 | N. 43° W ...... | 80° E...... | 8 feet..... | Diabase .. ............ | |
| 192 | N. 53° W ...... | ...... . ... | .......... | ........................ | |
| 193 | N. 27° E....... | 55° N ..... | 4 feet..... | Diabase ............... | Chasm. |
| 194 | N. 53° W ..... | 90°.. .... | 5 feet..... | ......do ...... .......... | |
| 195 | N. 38° W ...... | 85° E...... | 10 feet.... | .... .do ................ | |
| 196 | N. 42° E....... | ............ | 30 feet ... | Altered porphyritic diabase. | Same as 187 (?) Irregular. |
| 197 | N. 83° W .. ... | ............ | 20 feet.... | Diabase ............... | |
| 198 | N. 32° E....... | 70° N ..... | 14 feet ... | ......do ................ | |
| 199 | N. 47° E. ..... | ............ | ½ inch to 1½ feet. | ........................ | |
| 200 | N. 53° W ...... | ............ | 3 feet..... | Diabase ............... | Irregular. |
| 201 | N. 47° E....... | ............ | .......... | Altered diabase......... | |
| 202 | N. 57° E....... | 70° N ..... | 10 feet.... | Diabase ............... | |
| 203 | N. 77° E.... .. | 70° N ..... | 5½ feet.... | ......do ........... ..... | |
| 204 | N. 37° E....... | 45° N ..... | 2½ feet.... | ......do ............ .... | Disappears. |
| 205 | N. 82° E.. ... | 80° N ..... | 22 feet.... | ......do ....... ... .... | |
| 206 | N. 58° W ...... | 75° W..... | 2 feet..... | ......do ................ | |
| 207 | N. 58° W ..... | 90°........ | 2½ feet ... | ....... ................ | |
| 208 | N. 78° W ...... | 75° N ..... | 2½ feet.... | Feldspar porphyry ..... | |
| 208a | N. 28° W ...... | 65° NE.... | 6 feet..... | ..... do ......... ....... | |
| 208b | N. 28° W ...... | 80° NE.... | 12 feet.... | ......do ................ | |
| 209 | N. 47° W ...... | 75° NE ... | 2 feet..... | Diabase ............... | |
| 210 | N. 29° W . .... | 75° NE.... | 4 feet..... | ......do ................ | |
| 210a | N. 38° W ..... | 80° NE.... | 3 feet..... | ......do ................ | |
| 210b | N. 33° W ...... | 75° NE.... | 3 feet..... | ......do ................ | |
| 211 | N. 43° W ..... | 80° NE.... | 3 feet..... | ........................ | |
| 211a | N. 43° W .... | 80° NE.... | 1½ feet.... | ...... ............... | |
| 212 | N. 33° W ... | 80° NE.... | 18 to 20 feet | Very augitic diabase.... | |
| 213 | N. 38° W . .... | ............ | 3 to 4 feet . | ........................ | |
| 214 | N. 37° E. .... | ............ | .......... . | Feldspar porphyry .... | Very irregular. |
| 215 | N. 23° W .. ... | 80 to 85° E. | 15 feet.... | Diabase .. ............ | |
| 216 | N. 48° W ...... | ............ | 3 feet..... | ......do ..... ... ....... | |
| 217 | N. 77° E. . ... | 70° N ..... | 4 feet..... | ......do ................ | |
| 218 | N. 28° W ...... | 90°........ | 9 feet..... | ......do ................ | |
| 219 | N. 77° E.. . .. | 50° N ..... | 1½ feet.... | Diorite (?) ............ | |
| 220 | N. 33° W ...... | 85° E...... | 1 foot..... | .. ................ ...... | |
| 221 | N. 13° W ...... | ............ | 1½ feet.... | Diabase ............... | |
| 222 | N. 77° E....... | ............ | .......... | ........................ | |
| 223 | N. 58° W ...... | 80 to 85° NE | 3 feet..... | ........................ | |
| 224 | N. 38° W ...... | 85° NE.... | 1½ feet ... | ...................... ..... | |

*List of dikes of Cape Ann*—Continued.

| No. on map. | Strike. | Dip. | Width. | Name. | General remarks. |
|---|---|---|---|---|---|
| 225 | N. 33° W | | 2 feet | | |
| 226 | N. 50° W | 90° | 9 feet | | |
| 227 | N. 43° W | 50° NE | 10 feet | Quartz porphyry | |
| 228 | N. 33° W | 90° | 3 feet | Diabase | A bow-shaped dike. |
| 228[a] | N. 83° E | 90° | 3 feet | do | do. |
| 229 | N. 33° W | 90° | 3 feet | do | |
| 230 | N. 37° W | 80° W | 30 feet | | |
| 231 | N. 13° W | | 5 to 10 feet. | Diabase | |
| 232 | N. 39° W | 80° NE | 3 feet | do | |
| 233 | N. 31° W | 90° | 2½ feet | Feldspar porphyry | |
| 234 | N. 13° W | | | Diabase | Very irregular. |
| 235 | N. 31° W | 80° NE | 9 feet | Feldspar porphyry | |
| 236 | N. 23° W | 85° NE | 1½ feet | Diabase | |
| 237 | N. 37° E | | | Diorite porphyrite | |
| 238 | N. 33° W | | 1½ feet | Diabase | |
| 239 | N. 13° W | 90° | 3 feet | | |
| 240 | N. 13° W | 90° | 3 feet | | Cut by 241 and 241[a]. |
| 241 | N. 73° W | 75° N | 9 feet | Diabase | Irregular and very much branched. |
| 241[a] | N. 88° W | 75° N | 5 feet | do | do. |
| 241[b] | N. 58° W | | ⅝ inch | do | do. |
| 241[c] | N. 58° W | | 5 inches | do | do. |
| 241[d] | N. 58° W | | ½ to 5 inches | do | do. |
| 241[e] | N. 13° W | | 8 inches. | do | |
| 241[f] | N. 13° W | | 5 inches | do | |
| 242 | N. 33° W | 70° NE | 12 feet | do | |
| 243 | N. 33° W | 90° | 2½ feet | Porphyritic diabase | |
| 244 | N. 37° W | 70° NE | 4 to 5 inches | Diabase | Irregular. |
| 245 | N. 33° W | 80° NE | 1¾ feet | Quartz porphyry | |
| 246 | N. 28° W | 80° NE | 21 feet | Diabase (?) | |
| 247 | N. 33° W | 80° SW | 2½ feet | | |
| 247[a] | N. 33° W | 80° SW | 2 feet | | |
| 247[b] | N. 43° to 63° W. | | 2 feet | | |
| 247[c] | N. 33° to 68° W. | | | | Joining 247[d]. |
| 247[d] | N. 33° W | 80° SW | 3 feet | | |
| 248 | N. 43° W | | ½ to 2 feet. | Diabase | |
| 249 | N. 38° W | 90° | 3 feet | do | |
| 250 | N. 43° W | 75 to 80° SW. | 4 feet | | |
| 251 | N. 48° W | 80° S | 3 inches | | |
| 252 | N. 37° W | 80° SW | 3 to 4 feet. | Diabase | |
| 252[a] | N. 23° W | 85° SW | 15 inches | | |
| 253 | N. 33° W | 90° | 1 foot | | |
| 254 | N. 48° W | 80° SW | 3 feet 3 inches. | Diabase | |
| 255 | N. 33° W | 90° | 10 feet | do | |
| 256 | N. 53° W | 88° S | 4 feet | do (?) | |
| 257 | N. 13° W | 25° E | 3½ feet | do | |
| 258 | N. 35° W | 75° E | 15 feet + | do | |
| 259 | N. 37° W | 75° NE | 3½ feet | do | |
| 260 | N. 45° W | 90° | 3 feet | | |
| 261 | N. 25° W | 70° NE | 3 feet | | |
| 262 | N. 38° W | | 15 feet + | | |
| 263 | N. 29° W | | 2 feet | | |
| 264 | N. 33° W | | 10 feet + | Diabase | |

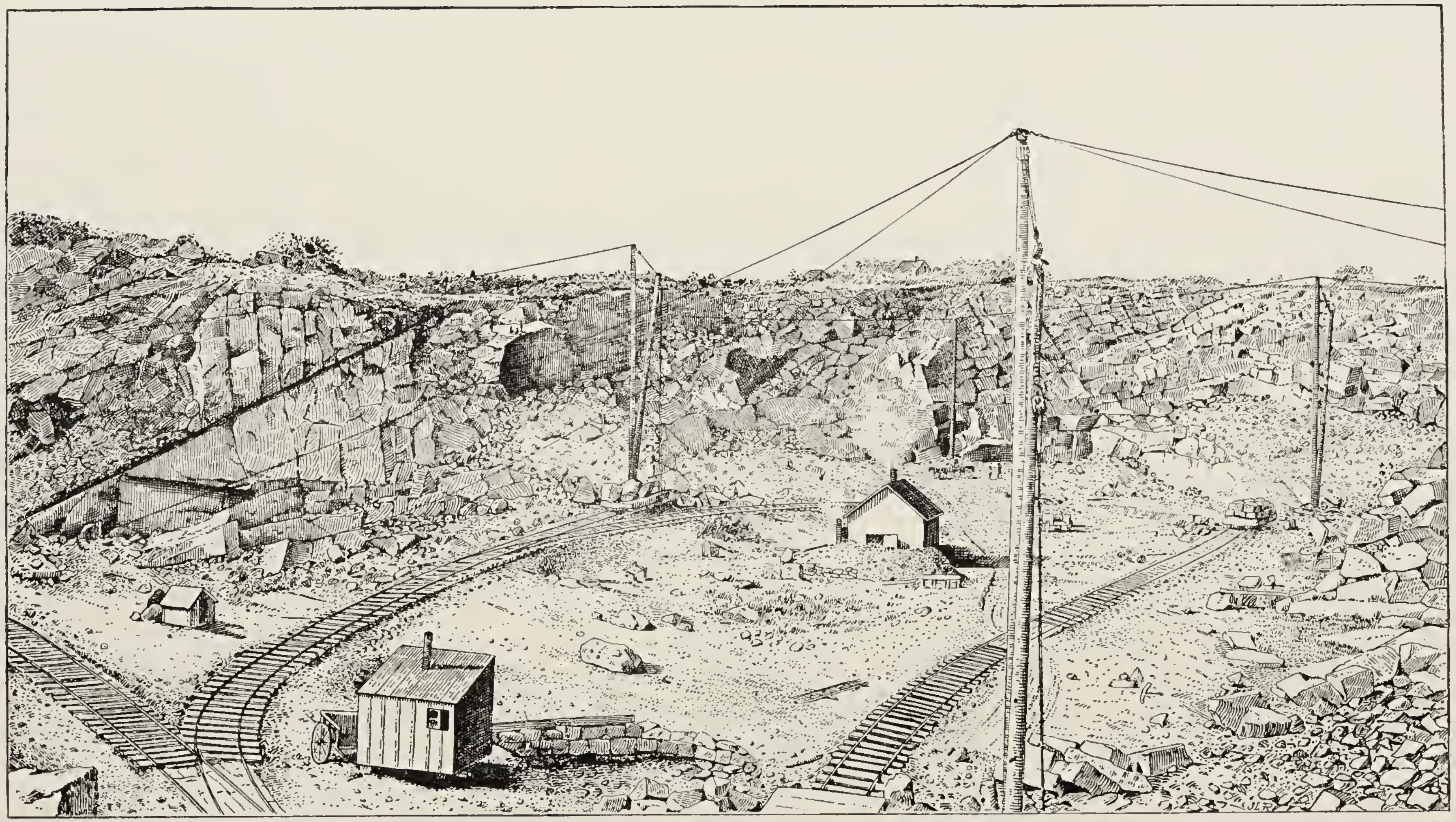
PIGEON HILL QUARRY UPPER PIT, SHOWING EXTREME DEVELOPMENT OF HORIZONTAL JOINTING.

*List of dikes of Cape Ann*—Continued.

| No. on map. | Strike. | Dip. | Width. | Name. | General remarks. |
|---|---|---|---|---|---|
| 265 | N. 53° W | | 3 to 5 feet. | Diabase | |
| 266 | N. 31° W | 80° NW | 10 to 15° | do | |
| 267 | N. 17° E | 50° E | | do | |
| 268 | N. 27° W | 85° NE | 3½ feet | do | |
| 269 | N. 33° to 53° W. | | 15 feet | Diorite (?) | |
| 270 | N. 25° W | 70° NE | | | |
| 271 | N. 13° W | 70° E | | | |
| 272 | N. 31° W | | 12 feet | Diabase | |
| 273 | N. 43° W | 80° SW | 2 feet | do | |
| 274 | N. 23° W | 70° NE | 15 feet | do | |
| 275 | N. 13° W | 75° NE | 15 feet | do | |
| 276 | N. 58° W | | 35 feet | do | |
| 277 | N. 58° W | | 10 feet | Diorite | |
| 278 | N. 33° W | | 15 feet | Diabase | Cuts 276. |
| 279 | N. 33° W | 90° | 18 feet | do | |
| 280 | N. 33° W | | 20 to 25 feet | | |
| 281 | N. 33° W | | 3 to 5 feet | Diabase | |
| 282 | | | | do | |
| 283 | N. 8° W | 75° E | 15 feet | do | |
| 283[a] | N. 1° W | 70° E | 1 foot | do | |
| 283[b] | N. 28° W | 90° | 9 inches | do | |
| 284 | N. 77° E | 90° | 6 inches | do | |
| 285 | N. 63° W | 90° | 3½ feet | do | Disappears. |
| 286 | N. 33° W | 90° | 3½ feet | do | |
| 287 | | | | do | |
| 288 | N. 21° W | 80° E | 1½ feet | | |
| 289 | N. 13° W | 85° E | 3½ feet | | |
| 290 | N. 28° W | | 4 feet | Diabase | |
| 291 | N. 9° W | 80° NE | 3 feet | do | |
| 292 | N. 13° W | | 3 inches | | |
| 293 | N. 33° W | | 12 feet | | |
| 294 | N. 33° W | | 12 feet | Diabase | |
| 295 | N. 41° W | 60° NE | 3 feet+ | do | |
| 296 | N. 33° W | 60° SW | 3 feet+ | do | |
| 297 | N. 9° E | 70° NW | 2½ feet | do | |
| 298 | N. 43° W | 60° NE | 6 feet | | |
| 299 | N. 63° W | 90° | 3 feet | Diabase | |
| 300 | N. 12° E | 80° NW | 3½ feet | do | |
| 301 | N. 23° W | | 3 feet | do | |
| 302 | N. 33° W | 75° NE | 2 feet 3 inches. | do | |
| 303 | N. 48° W | | 6 feet | do | |
| 304 | N. 13° W | 85° W | 3 feet | do | |
| 305 | N. 28° W | | | do | |
| 306 | N. 13° W | 80° E | 15 feet | do | |
| 307 | N. 38° W | 70° E | 9 feet | | |
| 308 | N. 62° E | 75° N | | Diabase | |
| 309 | N. 21° W | 90° | | do (?) | |
| 310 | N. 1° W | 90° | 2 feet | | |
| 311 | N. 13° W | 90° | 3 feet | | |
| 312 | N. 57° E | 80° NW | 3 feet | | |
| 313 | N. 28° W | 90° | 3 feet | Diabase | |
| 314 | N. 13° W | | 12 feet | | |
| 315 | N. 33° W | 82° NE | 10 inches | Diabase | |

*List of dikes of Cape Ann*—Continued.

| No. on map. | Strike. | Dip. | Width. | Name. | General remarks. |
|---|---|---|---|---|---|
| 316 | N. 35° W | 85° W. | 5½ feet | Diabase | Cuts 317. |
| 317 | N. 23° W | 75 to 85° E. | 3 feet | do | |
| 318 | N. 67° W | 30° SW | 1¼ feet | do | |
| 319 | N. 21° W | 82° E. | 2½ feet | do | |
| 320 | N. 77° E. | 65° N | 2 feet | do | |
| 321 | N. 87° E. | 68° NE. | 1 foot | do | |
| 322 | N. 88° W | 67° NE. | 21 feet | do | |
| 323 | N. 18° W | 69° NE. | 3 feet | do | |
| 324 | N. 35° W | 84° NE. | 2 inches | do | |
| 325 | N. 8° W | 75° NE. | 1 foot | Porphyritic diabase | |
| 326 | N. 22° W | 68 to 80° E. | 6 feet | do | |
| 327 | N. 23° W | 48° NE. | 2 feet | Diabase | |
| 328 | N. 8° W | 70° NE. | 2 feet | do | |
| 329 | N. 51° W | 64° E. | 4 inches | do | |
| 330 | N. 78° E. | 80° N | 3 inches | do | |
| 331 | N. 43° W | 75° W. | 1 foot | do | |
| 332 | N. 55° W | 76° W. | 1½ feet | do | |
| 333 | N. 37° E. | 66° N | 1 foot | do | Cut by 331 and 332. |
| 334 | N. 48° W | 75° E. | 1 foot | do | |
| 335 | N. 3° W | 90° | 1 foot | do | |
| 336 | N. 36° W | 82° W. | 3 feet 4 inches. | do | |
| 337 | N. 28° W | 86° W. | 3 feet | do | |
| 338 | N. 85° W | 90° | 10 feet | do | |
| 339 | N. 46° W | 64° NE. | 2 inches | Porphyritic diabase | |
| 340 | N. 66° W | 83° NE. | 2 feet | Diabase | |
| 341 | N. 57° E. | | 25 feet | do | |
| 342 | N. 5° W | 40° NE. | | | |
| 343 | N. 53° W | 90° | 2 feet | Diabase | |
| 344 | N. 43° W | 90° | 1 foot | do | Disappears. |
| 345 | N. 22° W | 72° E. | 2 feet | do | |
| 346 | N. 28° W | 75° NE. | 2½ feet | do | |
| 347 | N. 81° W | 65° NE. | 18 feet | do | |
| 348 | N. 3° to 28° W. | 83° NE. | 9 feet | do | Cut by 349. |
| 349 | N. 20° E. | 61° NW | 15 inches | Porphyritic diabase | |
| 350 | N. 52° E. | 74° NW | 3 inches | Diabase | |
| 351 | N. 29° W | 86° NE. | 2 feet | do | |
| 352 | N. 11° E. | 80° NW | 6 feet | do | |
| 353 | N. 33° W | 60° NE. | 9 feet | do | |
| 354 | N. 28° W | 90° | 2 feet | do | |
| 355 | N. 36° W | 78° W. | 1½ feet | do | |
| 356 | N. 43° W | | | | |
| 357 | N. 43° W | 80° E. | 6 feet | | |
| 358 | N. 31° W | | 3 feet | | |
| 359 | N. 31° W | 80° NE. | ½ to 2½ feet. | Diabase | |
| 360 | N. 43° W | 70° NE. | 3 feet | do | |
| 361 | N. 28° W | 90° | 2½ feet | do | |
| 362 | N. 13° W | 80° NE. | 3½ feet | do | |
| 363 | N. 18° W | | 6 feet | do | |
| 364 | N. 37° W | | 3 to 4 feet. | do | |
| 365 | N. 21° W | 60° SW | 3 feet | do | |
| 366 | N. 16° W | 70° W. | 1½ feet | do | |



ROCKPORT GRANITE COMPANY'S QUARRY, SOUTH PIT, SHOWING GENERAL STRUCTURE OF ROCK AND ECONOMIC ORGANIZATION OF THE PIT; LOOKING WEST.

*List of observed joint planes.*

PIT I.

| No. of observation. | Strike. | Dip. | No. of observation. | Strike. | Dip. | No. of observation. | Strike. | Dip. |
|---|---|---|---|---|---|---|---|---|
| I. | N. 88° W. | 83½° N. | XVII. | N. 71° W. | 90° N. | XXXIII. | N. 33° W. | 85° NE. |
| II. | N. 82° W. | 90°. | XVIII. | N. 70° W. | 84° N. | XXXIV. | N. 24° W. | 82° E. |
| III. | N. 80° W. | 88° N. | XIX. | N. 70° W. | 86° N. | XXXV. | N. 23° W. | 75° E. |
| IV. | N. 79° W. | 83° N. | XX. | N. 69° W. | 82° N. | XXXVI. | N. 23° W. | 83° E. |
| V. | N. 79° W. | 90°. | XXI. | N. 69° W. | 84½° N. | XXXVII. | N. 23° W. | 84° E. |
| VI. | N. 78° W. | 85° N. | XXII. | N. 69° W. | 88° N. | XXXVIII. | N. 6° W.. | 83° E. |
| VII. | N. 78° W. | 85° N. | XXIII. | N. 68° W. | 84° N. | XXXIX. | N. 5° W.. | 75° E. |
| VIII. | N. 76° W. | 78° N. | XXIV. | N. 68° W. | 88° N. | XL. | N. 3° W.. | 82° E. |
| IX. | N. 75° W. | 84° N. | XXV. | N. 67° W. | 82° N. | XLI. | N. 3° W.. | 78° E. |
| X. | N. 74° W. | 55° N. | XXVI. | N. 61° W. | 81½° N. | XLII. | N. 3° W.. | 74° E. |
| XI. | N. 73° W. | 78° N. | XXVII. | N. 48° W. | 84° NE. | XLIII. | N. 2° W.. | 75° E. |
| XII. | N. 73° W. | 85° N. | XXVIII. | N. 48° W. | 90°. | XLIV. | N. 2° E... | 80° W. |
| XIII. | N. 72° W. | 82° N. | XXIX. | N. 47° W. | 83° NE. | XLV. | N. 9° E... | 83° W. |
| XIV. | N. 71° W. | 86° N. | XXX. | N. 43° W. | 85° NE. | XLVI. | N. 40° E.. | 84° NW. |
| XV. | N. 71° W. | 86° N. | XXXI. | N. 43° W. | 88° NE. | XLVII. | N. 47° E.. | 54° N. |
| XVI. | N. 71° N. | 87° N. | XXXII. | N. 33° W. | 80° NE. | XLVIII. | N. 48° E.. | 54° N. |

PIT II.

| No. of observation. | Strike. | Dip. | No. of observation. | Strike. | Dip. | No. of observation. | Strike. | Dip. |
|---|---|---|---|---|---|---|---|---|
| I. | E. and W. | 60° N. | XVI. | N. 24° W. | 90°. | XXXI. | N. 8° W.. | 72° E. |
| II. | N. 89° W. | 73° N. | XVII. | N. 23° W. | 85° E. | XXXII. | N. 30° E.. | 69° NW. |
| III. | N. 88° W. | 90°. | XVIII. | N. 23° W. | 84° W. | XXXIII. | N. 32° E.. | 65° NW. |
| IV. | N. 87° W. | 85° N. | XIX. | N. 23° W. | 72° E. | XXXIV. | N. 32° E.. | 70° NW. |
| V. | N. 81° W. | 84° N. | XX. | N. 23° W. | 71° E. | XXXV. | N. 32° E.. | 72° NW. |
| VI. | N. 81° W. | 83° N. | XXI. | N. 23° W. | 65° E. | XXXVI. | N. 32° E.. | 65° SE. |
| VII. | N. 79° W. | 82° N. | XXII. | N. 23° W. | 62° E. | XXXVII. | N. 35° E.. | 75° NW. |
| VIII. | N. 77° W. | 76° N. | XXIII. | N. 22° W. | 85° W. | XXXVIII. | N. 37° E.. | 70° NW. |
| IX. | N. 71° W. | 80° NE. | XXIV. | N. 22° W. | 80° W. | XXXIX. | N. 37° E.. | 68° SE. |
| X. | N. 63° W. | 74° NE. | XXV. | N. 21° W.. | 75° E. | XL. | N. 38° E.. | 70° SE. |
| XI. | N. 58° W. | 80° NE. | XXVI. | N. 21° W. | 70° E. | XLI. | N. 85° E.. | 85° S. |
| XII. | N. 28° W. | 84° W. | XXVII. | N. 21° W. | 65° E. | XLII. | N. 86° E.. | 90°. |
| XIII. | N. 28° W. | 82° W. | XXVIII. | N. 18° W. | 79° E. | XLIII. | N. 87° E.. | 86° S. |
| XIV. | N. 25° W. | 70° NE. | XXIX. | N. 16° W. | 81° W. | XLIV. | N. 87° E.. | 82° S. |
| XV. | N. 25° W. | 69° E. | XXX. | N. 13° W. | 80° W. | XLV. | N. 89° E.. | 58° N. |

PIT III.

| No. of observation. | Strike. | Dip. | No. of observation. | Strike. | Dip. | No. of observation. | Strike. | Dip. |
|---|---|---|---|---|---|---|---|---|
| I. | N. 89° W. | 79° N. | XII. | N. 58° W. | 80° SW. | XXIII. | N. 27° E.. | 70° NW. |
| II. | N. 89° W. | 85° S. | XIII. | N. 58° W. | 81° SW. | XXIV. | N. 37° E.. | 63° NW. |
| III. | N. 88° W. | 90°. | XIV. | N. 2° E... | 80° NW. | XXV. | N. 42° E.. | 65° NW. |
| IV. | N. 88° W. | 85° N. | XV. | N. 5° E... | 62° NW. | XXVI. | N. 50° E.. | 68° S. |
| V. | N. 88° W. | 85° N. | XVI. | N. 7° E... | 68° NW. | XXVII. | N. 52° E.. | 55° S. |
| VI. | N. 88° W. | 82° N. | XVII. | N. 12° E.. | 90° NW. | XXVIII. | N. 62° E.. | 65° S. |
| VII. | N. 88° W. | 78° N. | XVIII. | N. 12° E.. | 65° NW. | XXIX. | N. 77° E.. | 65° S. |
| VIII. | N. 86° W. | 83° N. | XIX. | N. 12° E.. | 65° NW. | XXX. | N. 82° E.. | 90°. |
| IX. | N. 83° W. | 85° N. | XX. | N. 12° E.. | 60° NW. | XXXI. | N. 82° E . | 90°. |
| X. | N. 83° W. | 80° N. | XXI. | N. 11° E.. | 65° NW. | XXXII. | N. 85° E.. | 76° N. |
| XI. | N. 81° W. | 78° N. | XXII. | N. 22° E.. | 85° NW. | XXXIII. | N. 87° E.. | 80° N. |

PIT IV.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| I. | N. 89° W | 82° S. | XII. | N. 58° W. | 68° NE. | XXIII. | N. 32° E.. | 84° NW. |
| II. | N. 88° W. | 78° S. | XIII. | N. 56° W. | 70° NE. | XXIV. | N. 32° E.. | 90°. |
| III. | N. 88° W. | 76° S. | XIV. | N. 43° W. | 80° NE. | XXV. | N. 35° E.. | 90°. |
| IV. | N. 88° W. | 70° S. | XV. | N. 2° E... | 55° SE. | XXVI. | N. 35° E.. | 90°. |
| V. | N. 88° W. | (?) | XVI. | N. 7° E... | 68° SE. | XXVII. | N. 37° E.. | 90°. |
| VI. | N. 87° W. | 80° S. | XVII. | N. 7° E... | 70° NW. | XXVIII. | N. 37° E.. | 90°. |
| VII. | N. 86° W. | 68° S. | XVIII. | N. 12° E.. | 45° NW. | XXIX. | N. 37° E.. | 75° NW. |
| VIII. | N. 85° W. | 75° S. | XIX. | N. 15° E.. | 55° NW. | XXX. | N. 37° E.. | 55° SE. |
| IX. | N. 85° W. | 72° S. | XX. | N. 17° E.. | 64° NW. | XXXI. | N. 39° E.. | 90°. |
| X. | N. 85° W. | 70° S. | XXI. | N. 22° E.. | 68° NW. | XXXII. | N. 57° E.. | 65° NW. |
| XI. | N. 83° W. | 68° S. | XXII. | N. 25° E.. | 68° NW. | | | |

PIT V.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| I. | N. 89° W. | 90°. | XIX. | N. 28° W. | 60° NE. | XXXVII. | N. 40° E.. | 55° NW. |
| II. | N. 88° W. | 90°. | XX. | N. 25° W. | 65° NE. | XXXVIII. | N. 47° E.. | 58° NW. |
| III. | N. 88° W. | 80° S. | XXI. | N. 25° W. | 55° NE. | XXXIX. | N. 47° E.. | 54° NW. |
| IV. | N. 87° W. | 90°. | XXII. | N. 23° W. | 78° NE. | XL. | N. 65° E.. | 90°. |
| V. | N. 63° W. | 55° NE. | XXIII. | N. 23° W. | 42° SW. | XLI. | N. 67° E.. | 84° S. |
| VI. | N. 58° W. | 62° NE. | XXIV. | N. 18° W. | 85° NE. | XLII. | N. 77° E.. | 85° S. |
| VII. | N. 55° W. | 85° NE. | XXV. | N. 18° W. | 68° NE. | XLIII. | N. 77° E.. | 65° N. |
| VIII. | N. 53° W. | 76° NE. | XXVI. | N. 15° W. | 80° NW. | XLIV. | N. 77° E.. | 40° S. |
| IX. | N. 51° W. | 58° NE. | XXVII. | N. 10° W. | 90°. | XLV. | N. 82° E.. | 90°. |
| X. | N. 48° W. | 77° NE. | XXVIII. | N. 8° W.. | 90°. | XLVI. | N. 83° E.. | 90°. |
| XI. | N. 48° W. | 44° NE. | XXIX. | N. 5° W.. | 90°. | XLVII. | N. 84° E.. | 90°. |
| XII. | N. 46° W. | 70° NE. | XXX. | N. 5° W.. | 90°. | XLVIII. | N. 85° E.. | 90°. |
| XIII. | N. 41° W. | 45° NE. | XXXI. | N. 3° W.. | 90°. | XLIX. | N. 85° E.. | 90°. |
| XIV. | N. 40° W. | 48° NE. | XXXII. | N. 3° W.. | 40° E. | L. | N. 87° E.. | 90°. |
| XV. | N. 33° W. | 79° NE. | XXXIII. | N. 7° E... | 58° NW. | LI. | N. 87° E.. | 83° S. |
| XVI. | N. 33° W. | 72° NE. | XXXIV. | N. 7° E... | 55° NW. | LII. | N. 88° E.. | 68° NW. |
| XVII. | N. 33° W. | 38° SW. | XXXV. | N. 27° E.. | 85° SE. | LIII. | N. 89° E.. | 70° NW. |
| XVIII. | N. 30° W. | 74° NE. | XXXVI. | N. 31° E.. | 82° SE. | | | |

PIT VI.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| I. | N. 81° W. | 90°. | XVII. | N. 25° W. | 60° SW. | XXXII. | N. 57° E.. | 82° S. |
| II. | N. 56° W. | 63° NE. | XVIII. | N. 23° W. | 72° NE. | XXXIII. | N. 67° E.. | 85° N. |
| III. | N. 53° W. | 40° NE. | XIX. | N. 23° W. | 65° E. | XXXIV. | N. 67° E.. | 82° S. |
| IV. | N. 53° W. | 38° SW. | XX. | N. 23° W. | 62° E. | XXXV. | N. 69° E.. | 75° S. |
| V. | N. 51° W. | 64° NE. | XXI. | N. 22° W. | 65° E. | XXXVI. | N. 71° E.. | 83° S. |
| VI. | N. 48° W. | 44° SW. | XXII. | N. 21° W. | 70° E. | XXXVII. | N. 72° E.. | 78° S. |
| VII. | N. 46° W. | 60° SW. | XXIII. | N. 18° W. | 60° E. | XXXVIII. | N. 75° E.. | 73° S. |
| VIII. | N. 45° W. | 74° NE. | XXIV. | N. 13° W. | 71° E. | XXXIX. | N. 77° E.. | 84° NW. |
| IX. | N. 43° W. | 83° NE. | XXV. | N. 3° W.. | 70° E. | XL. | N. 78° E.. | 80° NW. |
| X. | N. 43° W. | 75° NE. | XXVI. | N. and S. | 54° W. | XLI. | N. 79° E.. | 90°. |
| XI. | N. 43° W. | 80° SW. | XXVII. | N. 2° E... | 55° W. | XLII. | N. 79° E.. | 90°. |
| XII. | N. 42° W. | 82° SW. | XXVIII. | N. 27° E.. | 90°. | XLIII. | N. 81° E.. | 90°. |
| XIII. | N. 41° W. | 84° SW. | XXIX. | N. 32° E.. | 52° NW. | XLIV. | N. 82° E.. | 90°. |
| XIV. | N. 41° W. | 82° NE. | XXX. | N. 47° E.. | 60° NW. | XLV. | N. 83° E.. | 90°. |
| XV. | 40° W. | 68° NE. | XXXI. | N. 47° E.. | 50° NW. | XLVI. | N. 84° E.. | 90°. |
| XVI. | 31° W. | 39° SW. | | | | | | |

ROCKPORT GRANITE COMPANY'S MIDDLE QUARRY SHOWING FOLDINGS OF GRANITITE AT CONTACT WITH DIKE; LOOKING WEST.

PIT VII.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| I. | N. 33° W. | 85° W. | XIV. | N. 2° E... | 80° NW. | XXVII. | N. 34° E.. | 70° NW. |
| II. | N. 28° W. | 90°. | XV. | N. 5° E... | 80° NW. | XXVIII. | N. 35° E.. | 72° NW. |
| III. | N. 28° W. | 61° W. | XVI. | N. 7° E... | 78° NW. | XXIX. | N. 35° E.. | 58° NW. |
| IV. | N. 27° W. | 60° W. | XVII. | N. 7° E... | 64° NW. | XXX. | N. 37° E . | 90°. |
| V. | N. 24° W. | 84° W. | XVIII. | N. 15° E.. | 74° NW. | XXXI. | N. 37° E.. | 65° NW. |
| VI. | N. 23° W. | 60° W. | XIX. | N. 25° E.. | 76° NW. | XXXII. | N. 39° E. | 90°. |
| VII. | N. 17° W. | 85° E. | XX. | N. 25° E.. | 70° NW. | XXXIII. | N. 72° E.. | 77° S. |
| VIII. | N. 17° W. | 80° W. | XXI. | N. 27° E.. | 68° NW. | XXXIV. | N. 77° E.. | 90°. |
| IX. | N. 14° W. | 90°. | XXII. | N. 29° E.. | 80° NW. | XXXV. | N. 77° E.. | 49° S. |
| X. | N. 13° W. | 76° W. | XXIII. | N. 29° E.. | 68° NW. | XXXVI. | N. 82° E.. | 75° N. |
| XI. | N. 3° W.. | 60° W. | XXIV. | N. 31° E.. | 90°. | XXXVII. | N. 87° E . | 90°. |
| XII. | N. 1° W.. | 78° W. | XXV. | N. 32° E.. | 90°. | XXXVIII. | N. 87° E.. | 90°. |
| XIII. | N. 2° E... | 82° NW. | XXVI. | N. 34° E.. | 90°. | | | |

PIT VIII.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| I. | N. 58° W. | 84° NE. | V. | N. 33° W. | 72° SW. | VIII. | N. 52° E. | 80° NW. |
| II. | N. 53° W. | 60° SW. | VI. | N. 47° E.. | 80° N. | IX. | N. 54° E.. | 79° NW. |
| III. | N. 45° W. | 65° NE. | VII. | N. 48° E.. | 79° NW. | X. | N. 59° E.. | 75° NW. |
| IV. | N. 38° W. | 75° NE. | | | | | | |

PIT IX.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| I. | N. 75° W. | 83° SE. | IX. | N. 51° E . | 90°. | XV. | N. 60° E.. | 72° NW. |
| II. | N. 71° W. | 82° SE. | X. | N. 51° E.. | 78° SW. | XVI. | N. 63° E.. | 81° N. |
| III. | N. 65° W. | 75° E. | XI. | N. 55° E.. | 77° N. | XVII. | N. 65° E.. | 74° N. |
| IV. | N. 61° W. | 80° E. | XII. | N. 57° E.. | 80° N. | XVIII. | N. 69° E.. | 79° N. |
| VI. | N. 28° W. | 70° E. | XIII. | N. 59° E. | 90°. | XIX. | N. 70° E.. | 78° SE. |
| VII. | N. 25° W. | 70° E. | XIV. | N. 59° E.. | 80° S. | XX. | N. 71° E. | 71° S. |
| VIII. | N. 23° W. | 71° E. | | | | | | |

PIT X.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| I. | N. 76° W. | 83° N. | VIII. | N. 31° E.. | 70° NW. | XV. | N. 70° E. | 72° S. |
| II. | N. 76° W. | 76° N. | IX. | N. 34° E.. | 67° NW. | XVI. | N. 70° E. | 75° S. |
| III. | N. 32° W. | 83° E. | X. | N. 47° E.. | 81° NW. | XVII. | N. 71° E.. | 54° N. |
| IV. | N. 23° W. | 90°. | XI. | N. 48° E.. | 83° SE. | XVIII. | N. 75° E.. | 70° S. |
| V. | N. 15° W. | 80° SW. | XII. | N. 66° E.. | 81° S. | XIX. | N. 77° E.. | 73° S. |
| VI. | N. 10° E.. | 45° NW. | XIII. | N. 69° E.. | 70° S. | XX. | N. 84° E.. | 90°. |
| VII. | N. 27° E.. | 70° SE. | XIV. | N. 70° E.. | 83° S. | XXI. | N. 86° E.. | 82° S. |

PIT XI.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| I. | E. and W. | 90°. | IX. | N. 52° W | 87° SW. | XVI. | N. 32° E.. | 90°. |
| II. | N. 83° W. | 90°. | X. | N. 52° W. | 70° NE | XVII. | N. 32° E.. | 80° NW. |
| III. | N. 66° W. | 83° N. | XI. | N. 52° W. | 87° SW. | XVIII. | N. 34° E. | 81° SE. |
| IV. | N. 61° W. | 48° NE. | XII. | N. 48° W. | 82° NE. | XIX. | N. 37° E.. | 62° NW. |
| V. | N. 58° W. | 80° NE. | XIII. | N. 46° W. | 90°. | XX. | N. 39° E.. | 75° N. |
| VI. | N. 56° W. | 80° NE. | XIV. | N. 2° E... | 64° E. | XXI. | N. 47° E.. | 65° NW. |
| VII. | N. 54° W. | 87° NE. | XV. | N. 22° E.. | 64° NW. | XXII. | N. 49° E.. | 80° SE. |
| VIII. | N. 53° W. | 90°. | | | | | | |

PIT XII.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| I. | N. 83° W. | 73° SW. | XVIII. | N. 23° W. | 90°. | XXXV. | N. 29° E.. | 85° NW. |
| II. | N. 75° W. | 73° NE. | XIX. | N. 13° W. | 54° W. | XXXVI. | N. 30° E.. | 83° NW. |
| III. | N. 67° W. | 85° NE. | XX. | N. 3° W.. | 58° NW. | XXXVII. | N. 32° E.. | 83° NW. |
| IV. | N. 66° W. | 90°. | XXI. | N. 1° W.. | 64° NW. | XXXVIII. | N. 32° E.. | 63° NW. |
| V. | N 66° W. | 76° NE. | XXII. | N. 2° E... | 71° SW. | XXXIX. | N. 34° E | 68° NW. |
| VI. | N. 66° W. | 64° NE. | XXIII. | N. 9° E... | 60° NW. | XL. | N. 37° E.. | 90°. |
| VII. | N. 63° W. | 83° N. | XXIV. | N. 12° E.. | 60° NW. | XLI. | N. 37° E. | 76° NW. |
| VIII. | N. 60° W | 90°. | XXV. | N. 17° E. | 64° NW. | XLII. | N. 39° E.. | 90°. |
| IX. | N. 58° W | 88° NE. | XXVI. | N. 17° E.. | 78° NW. | XLIII. | N. 39° E.. | 62° NW. |
| X. | N. 56° W. | 83° NE. | XXVII. | N. 20° E.. | 78° NW. | XLIV. | N. 40° E.. | 86° NW. |
| XI. | N. 53° W. | 81° NE. | XXVIII. | N. 20° E.. | 62° NW. | XLV. | N. 41° E . | 90°. |
| XII. | N. 53° W. | 78° SW. | XXIX. | N. 22° E.. | 69° SE. | XLVI. | N. 41° E.. | 73° NW. |
| XIII. | N. 46° W. | 70° NE. | XXX. | N. 24° E.. | 90°. | XLVII. | N. 41° E. | 58° NW. |
| XIV. | N. 45° W. | 75° NE. | XXXI. | N. 25° E.. | 84° NW. | XLVIII. | N. 42° E.. | 90°. |
| XV. | N. 44° W. | 80° NE. | XXXII. | N. 26° E.. | 90°. | XLIX. | N. 48° E.. | 78° NW. |
| XVI. | N. 36° W. | 68° NE. | XXXIII. | N. 26° E.. | 65° NW. | L. | N. 62° E.. | 83° NW. |
| XVII. | N. 33° W. | 73° NE. | XXXIV. | N. 27° E.. | 83° NW. | LI. | N. 66° E.. | 90°. |

PIT XIII.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| I. | N. 86° W. | 75° NE. | IX. | N. 30° W. | 87° NE. | XVI. | N. 20° E.. | 71° NW. |
| II. | N. 84° W. | 76° NE. | X. | N. 28° W. | 70° NE. | XVII. | N. 22° E.. | 84° SE. |
| III. | N. 83° W | 80° NE. | XI. | N. 12° W. | 80° NE. | XVIII. | N. 28° E.. | 78° SE. |
| IV. | N. 38° W. | 73° NE. | XII. | N. 8° W.. | 78° NE. | XIX. | N 30° E.. | 78° SE. |
| V. | N. 36° W | 78° NE. | XIII. | N. 17° E.. | 80° SE. | XX. | N. 48° E.. | 80° SE. |
| VI. | N. 34° W. | 85° NE. | XIV. | N. 17° E.. | 73° SE. | XXI. | N. 67° E.. | 90°. |
| VII. | N. 33° W. | 75° NE. | XV. | N. 20° E.. | 83° SE. | XXII. | N. 73° E.. | 75° S. |
| VIII. | N. 31° W. | 81° NE. | | | | | | |

PIT XIV.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| I. | N. 39° W. | 87° NE. | XV. | N. 34° E.. | 68° NW. | XXIX. | N. 59° E.. | 90°. |
| II. | N. 35° W. | 90°. | XVI. | N. 35° E.. | 90°. | XXX. | N. 59° E. | 90°. |
| III. | N. 33° W. | 90°. | XVII. | N. 37° E.. | 83° NW. | XXXI. | N. 60° E.. | 90°. |
| IV. | N. 18° W. | 90°. | XVIII. | N. 40° E.. | 90°. | XXXII. | N. 61° E.. | 79° NW. |
| V. | N. 25° E.. | 90°. | XIX. | N. 40° E.. | 84° NW. | XXXIII. | N. 62° E.. | 82° NW. |
| VI. | N. 28° E.. | 70° NW. | XX. | N. 40° E.. | 78° NW. | XXXIV. | N. 63° E.. | 90°. |
| VII. | N. 30° E.. | 84° SE. | XXI. | N. 40° E.. | 73° NW. | XXXV. | N. 67° E.. | 78° SE. |
| VIII. | N. 31° E. | 78° NW. | XXII. | N. 41° E.. | 74° NW. | XXXVI. | N. 71° E.. | 90°. |
| IX. | N. 32° E.. | 90°. | XXIII. | N. 47° E.. | 88° NW. | XXXVII. | N. 75° E. | 90°. |
| X. | N. 32° E.. | 90°. | XXIV. | N. 47° E. | 72° NW. | XXXVIII. | N. 77° E.. | 83° SE. |
| XI. | N. 32° E.. | 85° NW. | XXV. | N. 48° E.. | 90°. | XXXIX. | N. 77° E.. | 82° SE. |
| XII. | N. 32° E.. | 75° NW. | XXVI. | N. 49° E.. | 75° NW. | XL. | N. 83° E.. | 80° S. |
| XIII. | N. 32° E.. | 73° NW. | XXVII. | N. 50° E.. | 90°. | XLI. | N. 84° E.. | 83° N. |
| XIV. | N. 34° E.. | 78° NW. | XXVIII. | N. 58° E.. | 82° NW. | XLII. | N 87° E.. | 85° N. |

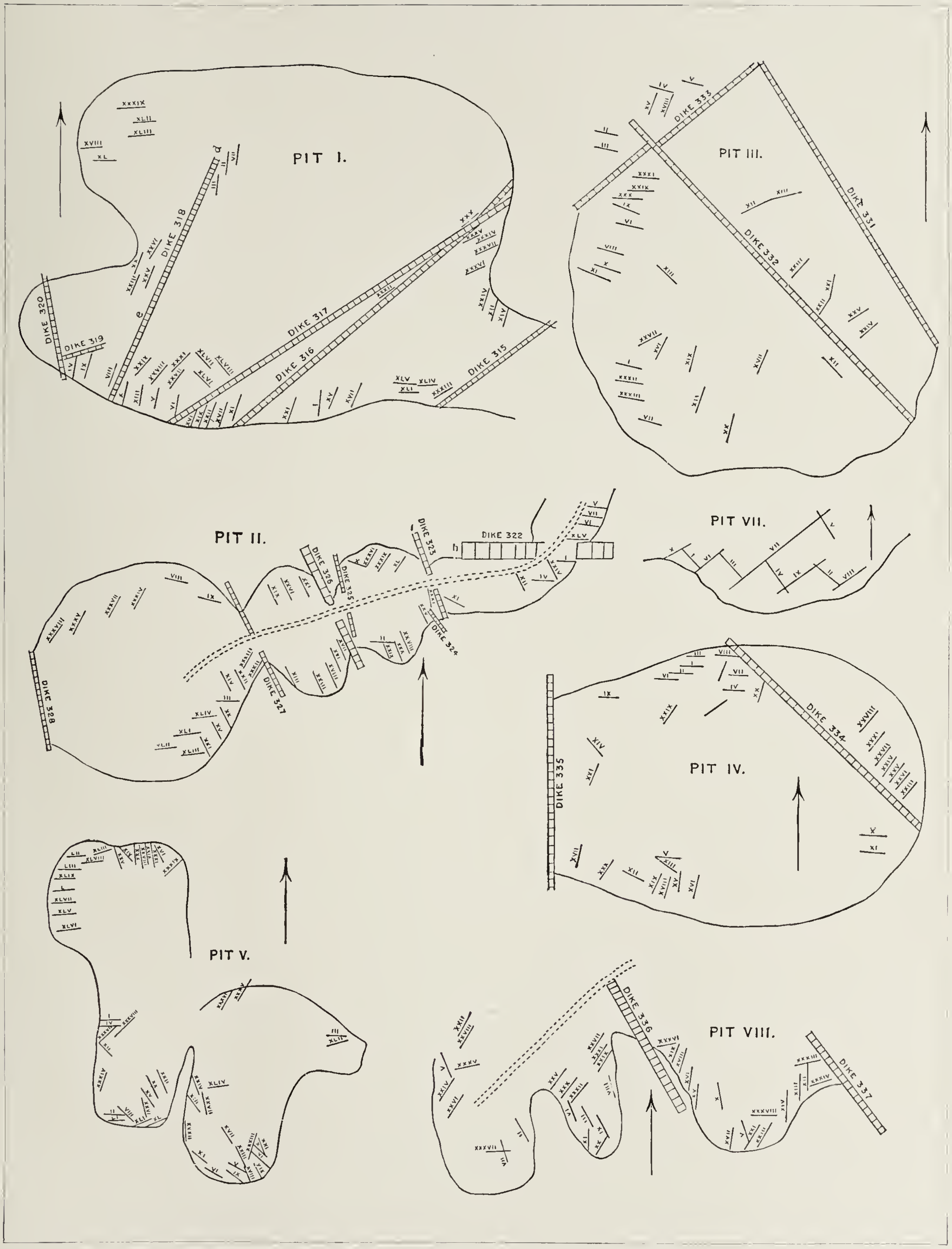



DIAGRAM SHOWING DISTRIBUTION OF DIKES AND JOINTS.

PIT XV.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| I. | N. 89° W. | 90°. | XIV. | N. 32° W. | 73° NE. | XXVII. | N. 47° E.. | 90°. |
| II. | N. 88° W. | 48 to 73° S | XV. | N. 32° W. | 72° NE. | XXVIII. | N. 47° E.. | 90°. |
| III. | N. 86° W. | 83° S. | XVI. | N. 31° W. | 75° NE. | XXIX. | N. 47° E.. | 90°. |
| IV. | N. 83° W. | 90°. | XVII. | N. 31° W. | 70° NE. | XXX. | N. 48° E.. | 90°. |
| V. | N. 83° W. | 90°. | XVIII. | N. 28° W. | 73° SW. | XXXI. | N. 50° E.. | 90°. |
| VI. | N. 73° W. | 85° SW. | XIX. | N. 28° W. | 71° NE. | XXXII. | N. 50° E.. | 90°. |
| VII. | N. 41° W. | 73° NE. | XX. | N. 28° W. | 82° NE. | XXXIII. | N. 52° E.. | 90°. |
| VIII. | N. 39° W. | 72° NE. | XXI. | N. 25° W. | 70° E. | XXXIV. | N. 57° E.. | 90°. |
| IX. | N. 37° W. | 70° NE. | XXII. | N. 23° W. | 83° E. | XXXV. | N. 62° E.. | 90°. |
| X. | N. 35° W. | 78° NE. | XXIII. | N. 19° W. | 82° E. | XXXVI. | N. 77° E.. | 90°. |
| XI. | N. 33° W. | 75° NE. | XXIV. | N. 32° E.. | 81° SE. | XXXVII. | N. 82° E.. | 80° SW. |
| XII. | N. 33° W. | 73° NE. | XXV. | N. 42° E.. | 80° NW. | XXXVIII. | N. 89° E.. | 90°. |
| XIII. | N. 33° W. | 72° NE. | XXVI. | N. 45° E.. | 90°. | XXXIX. | N. 89° E.. | 90°. |

PIT XVI.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| I. | N. 86° W. | 82° N. | XI. | N. 25° W. | 60° SW. | XXI. | N. 34° E.. | 70° NW. |
| II. | N. 86° W. | 78° N. | XII. | N. 23° W. | 78° SW. | XXII. | N. 36° E.. | 65° NW. |
| III. | N. 83° W. | 82° N. | XIII. | N. 11° E.. | 65° NW. | XXIII. | N. 37° E.. | 80° NW. |
| IV. | N. 83° W. | 80° N. | XIV. | N. 17° E.. | 62° NW. | XXIV. | N. 37° E.. | 72° NW. |
| V. | N. 81° W. | 81° N. | XV. | N. 18° E.. | 80° NW. | XXV. | N. 37° E.. | 70° NW. |
| VI. | N. 28° W. | 78° SW. | XVI. | N. 22° E.. | 63° NW. | XXVI. | N. 38° E.. | 70° NW. |
| VII. | N. 28° W. | 71° SW. | XVII. | N. 23° E.. | 69° NW. | XXVII. | N. 39° E.. | 62° NW. |
| VIII. | N. 28° W. | 70° SW. | XVIII. | N. 30° E.. | 70° NW. | XXVIII. | N. 70° E.. | 85° NW. |
| IX. | N. 26° W. | 58° SW. | XIX. | N. 32° E.. | 70° NW. | XXIX. | N. 88° E. | 80° N. |
| X. | N. 25° W. | 75° SW. | XX. | N. 34° E.. | 75° NW. | XXX. | N. 89° E.. | 80° N. |

PIT XVII.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| I. | N. 81° W. | 90°. | XII. | N. 23° W. | 90°. | XXIII. | N. 16° E.. | 75° NW. |
| II. | N. 81° W. | 87° N. | XIII. | N. 16° W. | 90°. | XXIV. | N. 17° E.. | 83° NW. |
| III. | N. 80° W. | 90°. | XIV. | N. 14° W. | 90°. | XXV. | N. 17° E.. | 81° NW. |
| IV. | N. 80° W. | 90°. | XV. | N. 7° E... | 75° NW. | XXVI. | N. 17° E.. | 70° NW. |
| V. | N. 78° W. | 90°. | XVI. | N. 11° E.. | 88° NW. | XXVII. | N. 17° E.. | 69° NW. |
| VI. | N. 78° W. | 85° N. | XVII. | N. 11° E.. | 83° NW. | XXVIII. | N. 20° E.. | 90°. |
| VII. | N. 76° W. | 90°. | XVIII. | N. 11° E.. | 81° NW. | XXIX. | N. 20° E.. | 71° SE. |
| VIII. | N. 73° W. | 85° N. | XIX. | N. 12° E.. | 78° NW. | XXX. | N. 22° E.. | 85° NW. |
| IX. | N. 37° W. | 80° NE. | XX. | N. 14° E.. | 80° NW. | XXXI. | N. 73° E.. | 90°. |
| X. | N. 25° W. | 90°. | XXI. | N. 14° E.. | 80° NW. | XXXII. | N. 74° E.. | 90°. |
| XI. | N. 25° W. | 84° E. | XXII. | N. 15° E.. | 78° NW. | XXXIII. | N. 77° E.. | 85° SE. |

PIT XVIII.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| I. | N. 88° W. | 81° N. | XII. | N. 11° E.. | 68° NW. | XXIII. | N. 48° E.. | 60° NW. |
| II. | N. 88° W. | 90°. | XIII. | N. 12° E.. | 60° NW. | XXIV. | N. 57° E.. | 83° SE. |
| III. | N. 88° W. | 79° S. | XIV. | N. 17° E.. | 73° NW. | XXV. | N. 62° E.. | 90°. |
| IV. | N. 86° W. | 85° S. | XV. | N. 17° E.. | 61° NW. | XXVI. | N. 64° E.. | 75° SE. |
| V. | N. 84° W. | 84° S. | XVI. | N. 17° E.. | 60° NW. | XXVII. | N. 67° E.. | 90°. |
| VI. | N. 82° W. | 80° S. | XVII. | N. 18° E.. | 61° NW. | XXVIII. | N. 86° E.. | 75° S. |
| VII. | N. 63° W. | 81° S. | XVIII. | N. 19° E.. | 75° NW. | XXIX. | N. 87° E.. | 76° S. |
| VIII. | N. 28° W. | 60° NE. | XIX. | N. 20° E.. | 65° NW. | XXX. | N. 87° E.. | 68° S. |
| IX. | N. 18° W. | 90°. | XX. | N. 20° E.. | 65° NW. | XXXI. | N. 89° E.. | 90°. |
| X. | N. 15° W. | 80° SE. | XXI. | N. 27° E.. | 69° NW. | XXXII. | N. 89° E.. | 81° S. |
| XI. | N. 7° E... | 63° NW. | XXII. | N. 30° E.. | 60° NW. | | | |

PIT XIX.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| I. | N. 89° W. | 90°. | VIII. | N. 33° W. | 68° NE. | XV. | N. 7° E... | 75° S. |
| II. | N. 68° W. | 68° SW. | IX. | N. 31° W | 70° NE. | XVI. | N. 47° E.. | 63° NW. |
| III. | N. 67° W. | 81° SW. | X. | N. 25° W. | 67° NE. | XVII. | N. 48° E.. | 62° NW. |
| IV. | N. 66° W. | 71° SW. | XI. | N. 23° W. | 64° NE. | XVIII. | N. 66° E.. | 68° NW. |
| V. | N. 63° W. | 78° SW. | XII. | N. 23° W. | 63° NE. | XIX. | N. 67° E.. | 72° SE. |
| VI. | N. 63° W. | 70° SW. | XIII. | N. 23° W. | 63° NE. | XX. | N. 82° E.. | 64° S. |
| VII. | N. 34° W. | 61° NE. | XIV. | N. 23° W. | 58° NE. | | | |

PIT XX.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| I. | N. 78° W. | 62° NE. | VI. | N. 1° W.. | 75° E. | X. | N. 67° E.. | 82° N. |
| II. | N. 73° W. | 55° SW. | VII. | N. 2° E... | 90°. | XI. | N. 69° E.. | 82° N. |
| III. | N. 58° W. | 78° SW. | VIII. | N. 2° E.. | 65° SE. | XII. | N. 70° E.. | 85° N. |
| IV. | N. 33° W. | 73° SW. | IX. | N. 49° E. | 60° NW. | XIII. | N. 77° E.. | 74° N. |
| V. | N. 7° W.. | 90°. | | | | | | |

## RIFTING OF THE QUARRIED ROCKS.

The quarried rocks of Cape Ann exhibit, as do those in other parts of the country, the phenomenon of "rifting" in an interesting manner. It is owing to the existence of this feature that the imperfectly jointed rocks of this region are so serviceable to the quarryman. By the term "rift" is indicated an incipient fracture in the rock which has not developed in the form of a joint plane. No very distinct passage has been seen between the incipient fracture of the rifting and the perfect joint planes. At one point between the two great quarries at Bay View, where the rift has been subjected to the action of the weather on the old glacial surface or on a surface which has been for some time bared to the weather, the rifting appears as visible fractures, not averaging more than a quarter of an inch apart and extending for a distance of two feet through the rock. In yet other cases, joints which have a development of chloritic and epidotic material on the side of the fracture, known to the quarrymen as "green seams," pass rather more distinctly into the rift planes than do the ordinary joints.

Quarrymen, for convenience of description, divide the rift lines along which their rock fractures into two divisions, which are generally found in quarries, viz, the "rift" and the "cut-off." The most manifest of these, whatever be the direction, they term the rift. A set of joints at an angle of about 65 degrees to the rift they call the "cut-off." Sometimes a third system of incipient fractures is found nearly horizontal, which they term "lift." No other planes of fractures save those three are found in the granites of Cape Ann. Indeed, the third line of fracture is more frequently absent than present.

The peculiar feature of all these incipient fractures is that they appear only where the rock has been exposed to the weather or to

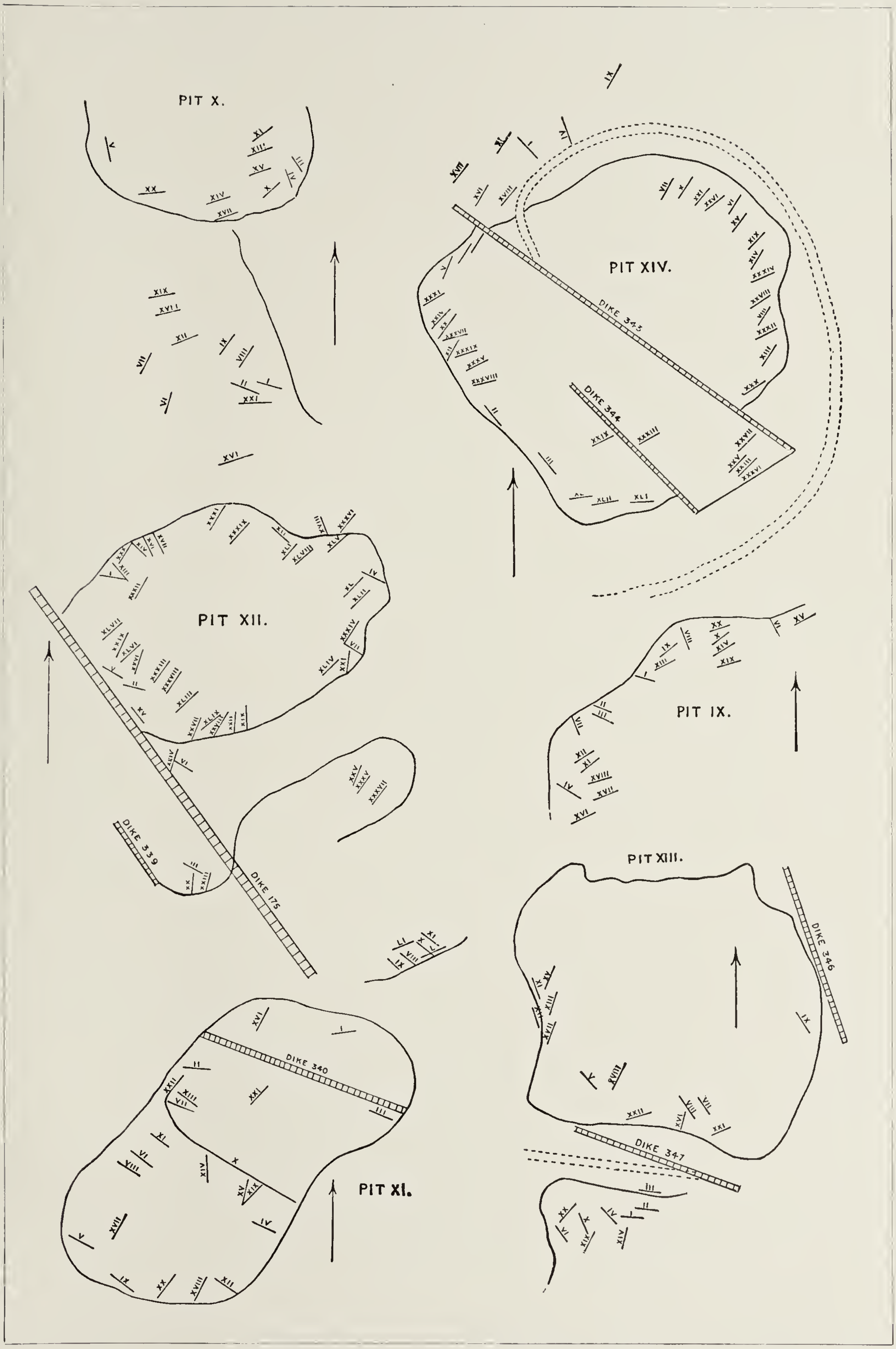



DIAGRAM SHOWING DISTRIBUTION OF DIKES AND JOINTS.

strain, while the joints, though not readily visible, appear evident on close inspection as far as the tendency to split on their planes extends.

When broken along the rift planes the faces of the fracture are much rougher than the faces exhibited by the deeper joint planes. This at first sight seemed to indicate that the character of the fractures and faults was essentially different from that artificially developed on the rift lines. It may be, however, that the processes of decay and replacement brought about by the action of the weather along the joint planes has caused this difference. It is also noticeable that where the rock is broken across the rift axes it commonly assumes the conchoidal fracture, and has in all cases the surface much more rough than that of the fractures which have developed along the rift planes. This is evidently due to the fact that in the conchoidal fracture the splitting turns around the crystals more than it does when the splitting is along the rift.

Although it is not yet certainly the case, it seems likely that there is a relation of a genetic sort between these fractures of the rift and those which are expressed in recognizable joint planes. In some of the quarries there is a manifest connection between the two. Thus in the Bay View quarries the most evident rift agrees exactly in direction with the most conspicuous set of joint planes. Elsewhere the relation can not be so well made out. It may be also noted that in one case the most evident rift plane on one side of a dike appeared to be indicated but extinguished on the other side of the intrusion.

Microscopic examination shows that the rifting probably occurs under the following conditions: The mass of granite, like that of other holo-crystalline rocks, is made up of material, all of which is arranged with reference to definite crystalline axes, but these axes are disposed in an entirely irregular manner. These crystals each have planes on which breakage will more readily occur than on other lines. Now, some of these crystals, the feldspar and hornblende at least, have lines along which they fracture with certain readiness. Such fracture planes are not known to exist with quartz, but it may also have axes on which breakage is somewhat more easy than in other planes. Moreover, in all these crystals, whatever the shape of their periphery, the line of juncture with the neighboring crystals is always somewhat irregular. Now, if a mass of this rock by strains is urged to fracture, the plane of rupture will be formed at some points by breaking through the crystal along its line of weakness, and in a general way coincide with the run of the rupture plane. In other cases the rupture will follow around the adjacent faces of the crystals. Microscopic sections show that something like this action has taken place. Along the lines of the rift where they cut through a feldspar crystal, although the evidence of displacement is obscure, the existence of a rupture is shown by the presence of a

distinct fault breccia, the fragments of the breccia having been afterwards cemented together with quartz, or, perhaps, by other minerals.

It seems likely that the amount of dislocation attendant on the formation of these fractures is extremely small, but this amount has not yet been determined. It seems also probable in all cases that the fracture is practically closed by the secretion of cement, which has bound the walls together. It may well have been that these several separate sets of fractures, those of the rift, the cut-off, and lift, were formed at different times, and were in turn more or less completely healed by exudations from the walls. Although these walls are at least in part fixed together, when the quarryman disrupts the mass, fractures more readily occur along these old planes than in any other direction.

The difficulty in identifying the rift structure with the joint planes arises from the fact that the joint planes are generally remote from each other in a far greater degree than those of the rifts, there being, in effect, no passage between the two classes of ruptures. If joint planes are genetically connected with rift planes, then it must have been that by the application of some force after the rifts were formed certain of the fracture lines at remote intervals were by secondary strains developed into joints.

Even if we could account, as it seems likely we may, for certain of the joint planes on this hypothesis, there remain, as the foregoing statements concerning joints show, many others which can not be referred to planes of rifting. It seems pretty clear that there is not an indefinite number of rift planes in the mass of the rock, while the number of positions of the joint planes is practically indefinite. Although the rift planes exist in a great portion of the rocks of Cape Ann there are some considerable irregularly disposed areas in the quarries, which appear in good part, if not entirely, destitute of these potential fracture lines. So far it has not been possible to secure any clue as to the relations of these non-rifted areas.

There is a practical point which comes out of this consideration concerning the value of rifts and joints to the quarryman's work. In general the joint planes of our crystalline rocks are disadvantageous to the quarryman. In certain cases they serve his needs, but oftener with a number of these fracture lines they break up the rock into inconvenient forms. Moreover, the joint planes, even where useful, are apt to become less distinct as depth is attained. On the other hand, the rift, though variable in amount and direction, appears to be a permanent feature in granitic rocks, and on the relation of the planes to each other depends in a large measure the serviceability of the material for architectural purposes. It therefore is well for persons undertaking costly work, connected with the stripping away of parts of the rock which are affected by water and other

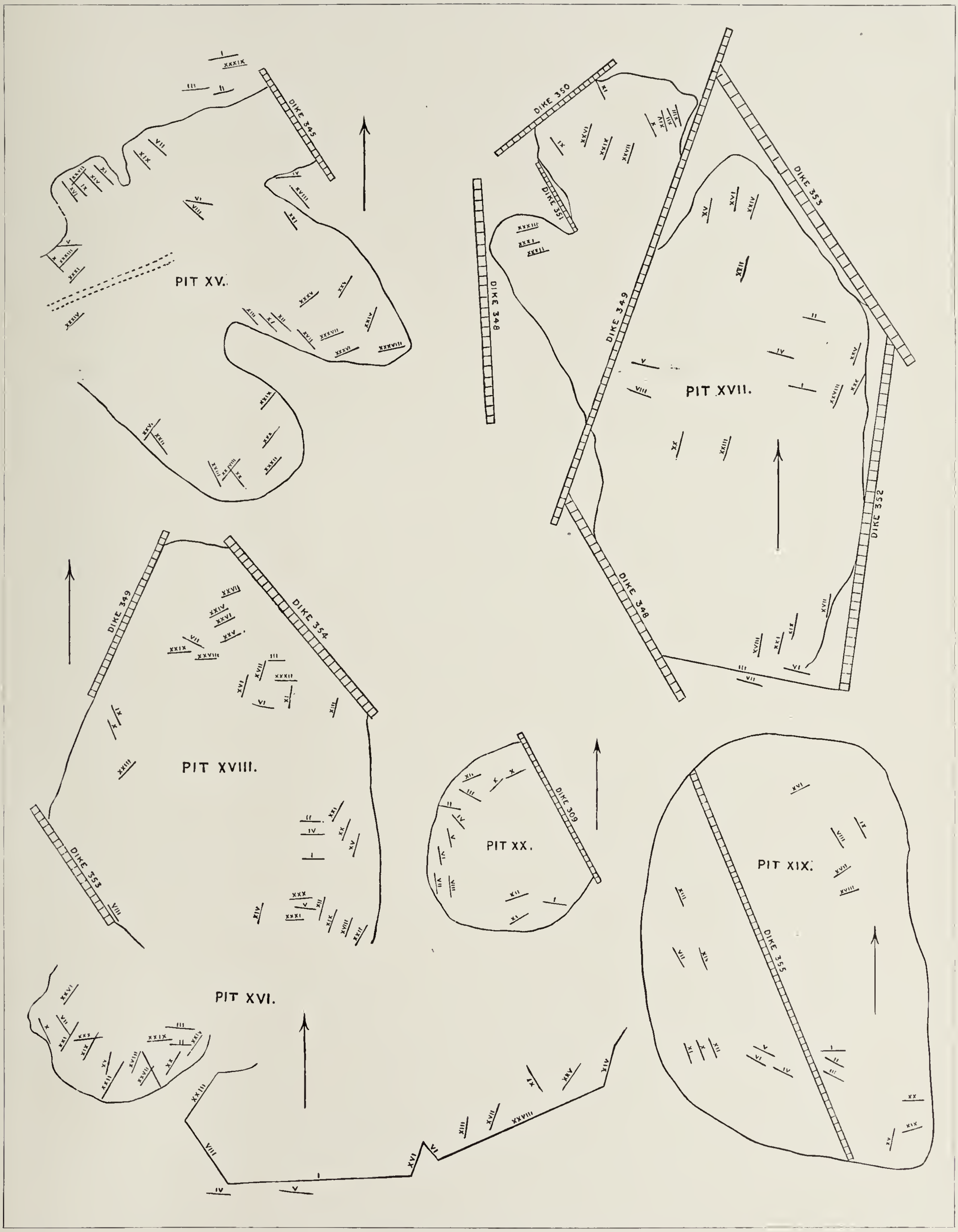



DIAGRAM SHOWING DISTRIBUTION OF DIKES AND JOINTS.

agents of superficial decay, to determine the character of the incipient rift fractures with reference to the end in view.

## THE GENERAL PETROGRAPHY OF CAPE ANN.

The bed rock on the island of Cape Ann is mainly granite cut in various directions by diabase and other dikes. This granite has been studied by several geologists, and has been called syenite, granite, and granitite. Dr. M. E. Wadsworth, who has made the most careful petrographic studies in this region, has decided the rock to be hornblendic granitite, and the studies made in preparation for this report point to the same conclusion. In a dozen microscopic slides cut from specimens collected at various points on the island a very nearly uniform character is observed. Quartz and orthoclase feldspar form the bulk of the rock, with black hornblende and biotite as the two other essential constituents. The feldspar is often microline. Both the quartz and feldspar are very much strained and broken, exhibiting distinct lines of weakness which develop the rift of the rock.

Besides these essential minerals we find the usual accessories of granite, plagioclase feldspar, magnetite, limenite, chlorite, apatite, zircon, epidote, and fluorite. The mineral danalite, which Dr. J. P. Cooke described from Rockport, also occasionally occurs. It resembles garnet in the slide, as well as when macroscopically examined.

All the quarries on Cape Ann are in rock having a uniform character as above described. At those exposures the biotite and hornblende vary somewhat in abundance ; but aside from this there is very little local modification in the character of the rock. On the sea shore, however, we observe that there are considerable variations in its texture and composition. In some places it is very fine grained ; again it becomes extremely coarse and almost porphyritic. In some cases the granite weathers easily; in others it is very durable. The rock often becomes very syenitic, and in one locality, in a railroad cut on the Eastern Railroad line, near the Magnolia station, the almost total absence of free quartz makes the rock, at least locally, a true syenite. It is possible that in some cases these variations may be caused by injections of granitic dikes through the bed rock; although in no case has it been possible to prove this hypothesis.

The islands lying near the shore—Milk, Salvages and Thatcher's—present a more difficult problem. Their complete isolation from the main mass and separation by a rather deep trough may indicate a line of weakness occupied by some more easily eroded rock, or perhaps may represent the line of contact of two distinct granitic injections. The petrographic evidence on this point is not complete. The bed rock on these several islands, while being essentially the same, differs widely in character from that on the mainland. Whether this

be due simply to local variations in the Cape Ann mass, or whether it marks a distinct ejection, has not been determined.

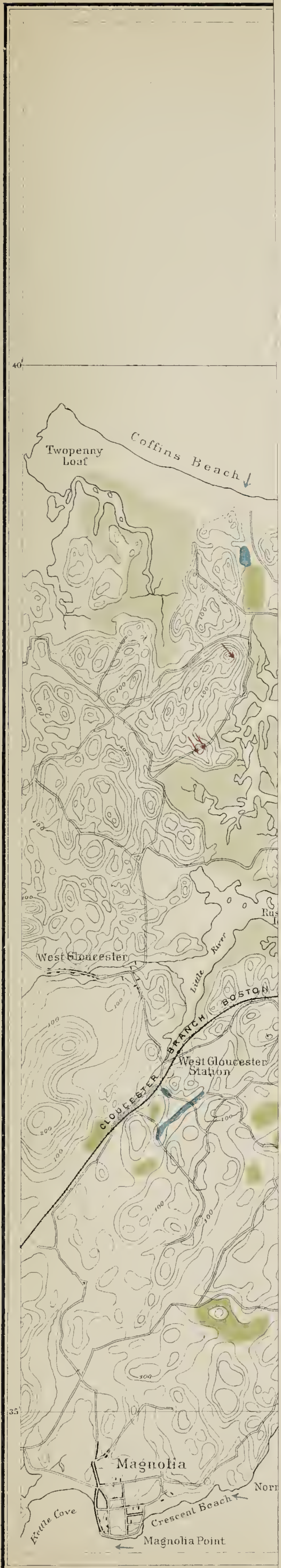
Macroscopically, the rock on the above-named islands differs from that on Cape Ann in being much darker, in the greater abundance of hornblende and magnetite, in containing much less quartz, and in having a darker colored feldspar. Quartz is quite common as minute crystalloids, and the feldspar often occurs in the form of Carlsbad twins and as microline. The general absence of macroscopic quartz is sufficiently well marked to place the rock among the syenitic granites. There is a frequent tendency to the porphyritic character. No distinction between these rocks has been made in the accompanying map of the bed rock.

In the vicinity of Squam River an area of diorite has been found occupying the position indicated upon the map. The depression occupied by Squam River is one of the most marked features in the topography of the region. On either side are high hills, and the center of the Reach is considerably below sea level, although it is much encumbered by glacial drift. To explain this valley was for a long time a difficult problem. It appeared quite evident that it must indicate a line of weakness in the granitite, though the nature of this remained undetermined. The general agreement between the trend of the valley, and the strike of the principal set of dikes and their abundance in that vicinity, suggested an explanation which lacked proof. For some time the presence of this diorite was unperceived, and it was considered a mere fine grained variation of the Cape Ann granitite.

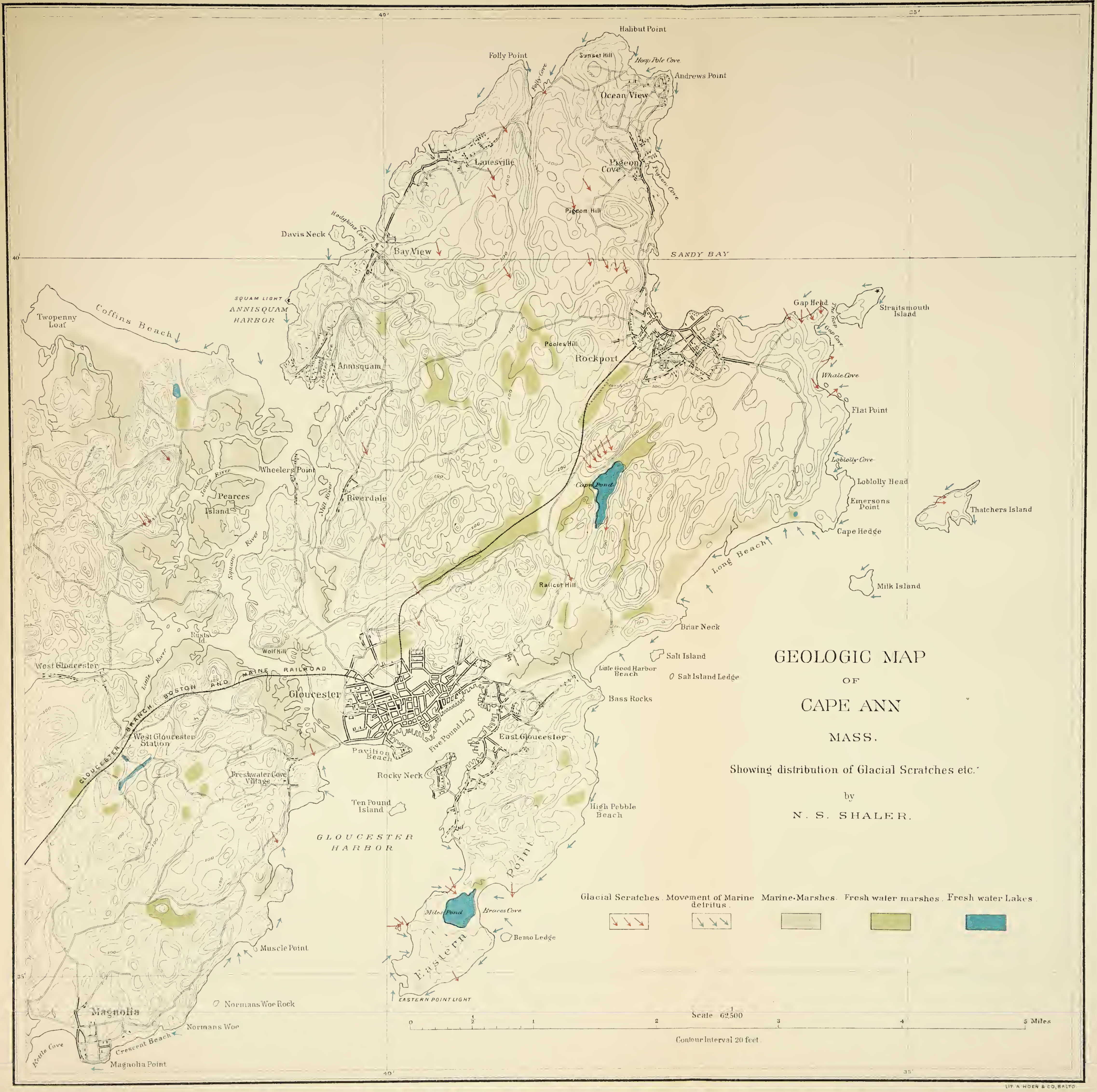
This diorite is very light colored, has a very glassy feldspar and some quartz, so that until the microscope was used its true character was undiscovered. The rock is finer grained than the granitite, is a trifle darker, and has a much more complicated development of joint planes. Instead of the great massive jointing so typical of granitite, the rock is cut into small blocks by numerous unsystematically arranged joint planes. This, however, served as no guide, for the granitite is occasionally cut by equally frequent joints.

Petrographically, the rock is composed of plagioclase feldspar, with much biotite and hornblende. Quartz is often very abundant, orthoclase feldspar, apatite, and zircon occur occasionally.

It is difficult to determine which of these two rocks is the older. The region is so drift-covered that the contact can not be seen; but wherever it is approached the granitite becomes markedly porphyritic; in some places, however, as for instance on the hill called "The Poles," in Gloucester, the diorite exhibits the same phenomenon. The contact effects are not uniformly well marked, which may be explained by the supposition that at the time of the injection of one of the masses the other was still very much heated. No dike of granitite has been found cutting the diorite, nor does this rock, so far



Twopenny Loaf
Coffins Beach
West Gloucester
Little River
BOSTON
BRANCH
GLOUCESTER
West Gloucester Station
Magnolia
Kettle Cove
Crescent Beach
Magnolia Point

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as observed, send tongues into the granitite. In several places, notably on the road to Coffin's Beach, and in the vicinity of Bond's Hill, on the west side of Squam River, opposite the city of Gloucester, the diorite is in such a position as to indicate that it is included in the granitite. Owing to the abundance of drift, this point in any of these localities can not be definitely settled. The first impression was that we had here a great dike of diorite cutting the granitite; but every indication in the field points to the opposite conclusion, namely, that the granitite has burst up around this diorite, leaving it as an included mass.

The mass of diorite is apparently of an irregularly circular form, having its center at about the middle of the Annisquam Reach on Rust's Island. On all sides where the rocks outcrop, it is surrounded by granitite, the two entrances of the Reach being the only places where it could possibly have cut the granitite. These entrances are narrow and are bounded on either side by granitite which is not porphyritic, which facts almost exclude the hypothesis that the diorite has cut the granitite. The porphyritic character of the granitite in many places is remarkably well developed; but nowhere better than at West Gloucester, near the Russian Cement Company's factory. The granite porphyry at this point has fine, large porphyritic crystals of quartz and feldspar in a ground mass composed mainly of the same minerals. It is very finely jointed, as may be seen in the picture of the post-glacial talus. (See Pl. L.) The approach of the diorite and granite is generally, though not invariably, marked by a distinct drift-filled valley. The granite as it approaches the contact is very much broken, and, even when not porphyritic, quite different from the typical Cape Ann granite.

The abundance of hornblende, the character of the feldspar, and the general absence of quartz, all render this rock open to the attack of the elements. This weakness is enhanced by the character of the jointing, both in this diorite and in the surrounding granite.

Some petrographic study has been given to the phenomena of inclusions, veins, segregations, dikes, decomposition and rift as observed in the granite of this island. Veins and segregations are both quite commonly found. In the Rockport quarry, pockets exist in the granite containing quartz and feldspar, intergrown to form the so-called graphic granite. In connection with these, are large nodules of smoky and milky quartz, masses of green feldspar, and small segregations of magnetite, frequently containing on their edges small, perfect prisms of zircon, terminated by pyramids with convex faces. Fluorite and danalite also occur in these veins in considerable masses. On the sea shore, little pockets and veins of graphic granite, blue quartz, feldspar, hornblende, and magnetite are often found, though they are by no means as common as in other regions on the New England coast.

Basic segregations, the "black patches" of the quarrymen, are met with in all the quarries. These are irregular, bluish patches, composed of feldspar and the more basic of the granitic constituents fading quite gradually into the true granitite. These patches represent the remnants of original segregations of the more basic elements from the granitic magma, before the final cooling of the mass. The variations in the hue, from a light blue to a very dark shade of the same color, depends upon the abundance of hornblende and magnetite which occur in fine grains scattered through the feldspar and quartz ground mass. In the slides, these basic segregations show the ordinary granite minerals in very fine grains, and in different proportions from that of the true granitite. Both orthoclase and plagioclase feldspar occur, the latter being rare; fine grained quartz is very abundant; hornblende and magnetite are common; and there is some biotite. The microperthite intergrowth of feldspar is extremely well shown, and Carlsbad twins are found everywhere. The effect of strain is shown in all the quartz grains of sufficient size.

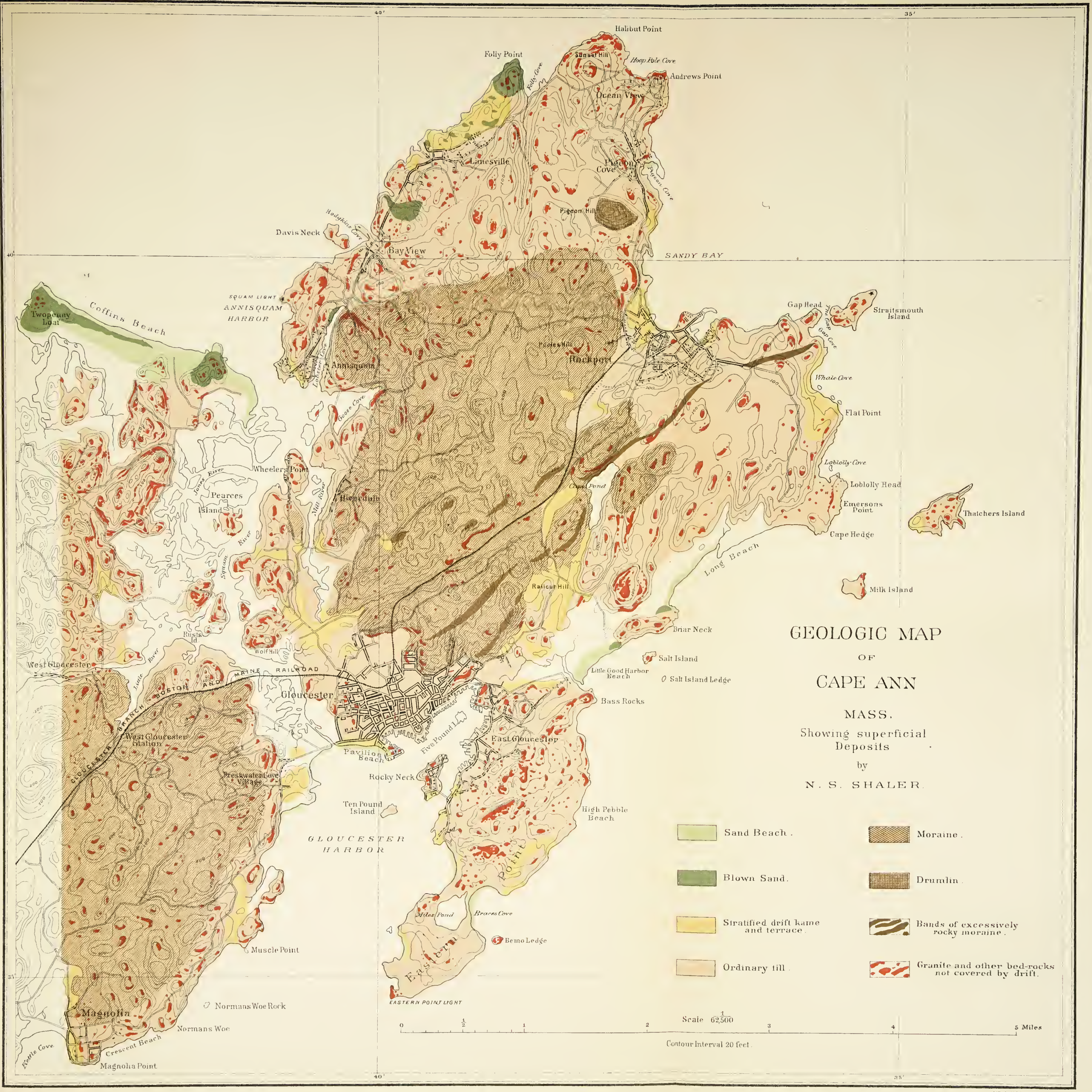
True inclusions of other rocks are not commonly met with in the granitic material. Near the contact of the granitite with the diorite in the West Gloucester district, apparent inclusions of diorite are common. In other parts of the region undoubted inclusions of dioritic and gneissoid rocks are found. Instances of the latter kind of inclusions were noticed on Davis' Neck, and at various other points along the Bay View and Lanesville shore. From the large number of included fragments, on this northwest shore of the island, one might be led to suspect that the locality is near the contact of the granitite with gneiss which may occupy the bed of Ipswich Bay.

Wherever any area of an acre or more of rock is bared by the waves, or by the quarryman's work, we find dike rocks cutting the granite. As before described, over three hundred and fifty dikes have been observed, mainly upon the sea shore line. The dikes, being more easily eroded than the granitite, seldom outcrop in the interior region. There can be no doubt that they are as abundant here as on the sea shore and their positions are often suggested by narrow drift-filled chasms in the granitite.

No thorough petrographic study has been made of any of these dikes; but a few of the more interesting ones have been subjected to a cursory microscopic examination. In general, it may be said that the dike rocks are either diabase or quartz porphyry, and these two general divisions only have been adopted in the accompanying map of the bed rock. Numerous subdivisions might be made upon the basis of the ground mass or special variations of mineral composition, but no attempt has been made to do so.

Dikes numbered on the map as follows have been found by a microscopic examination to be diabase: 5, 9, 57, 61, 91, 131, 150, 175, 201,


Twopenny Loaf
Coffins Beach
West Gloucester
Little River
BOSTON
BRANCH
GLOUCESTER
West Gloucester Station
Magnolia
Crescent Beach
Kettle Cove
Magnolia Point




LIT. A. HOEN & CO. BALTO.

217, 229, 264, 276, 277, and 299. They have the ordinary diabase composition, most being porphyritic; some holocrystalline; others cryptocrystalline. No signs of glass are present though the contact is often very fine grained and dense and may be composed of devitrification products. Lath-shaped plagioclase crystals are always present both as porphyritic crystals when the rock is porphyritic and in the ground mass. It is sometimes very clear and glassy; but more often somewhat decomposed. In some cases complete sausaurization results. Signs of paramorphism are not wanting. Brown and very pleochroic biotite is common as a primary constituent and also as a secondary product. It contains the usual diabase inclusions and alters readily to chlorite. Fine crystals of augite occur in the porphyrites, in some cases being pleochroic, but generally clear and colorless or pale green. The ground mass is frequently one-half augite. It decomposes readily to chlorite, green hornblende, magnetite, etc., until often no trace of it is left in the rock. This is the case in dikes Nos. 91 and 299. Muscovite, calcite, magnetite, iron pyrite, apatite, epidote and other products of decomposition are common in the slides made from all these dikes. In one case olivine was also present. No. 175 is a large dike of metamorphosed diabase porphyry 18 feet in width and extending several miles in Rockport and Pigeon Cove. It has extremely large plagioclase feldspar crystals several inches in length, often very much decomposed. The ground mass is holocrystalline, made up of very much decomposed lath-shaped plagioclase, hornblende, chlorite and magnetite mainly. The augite has almost completely disappeared in some cases, remaining simply as a core within a mass of green hornblende.

Only one dike, No. 237, has been studied, which can be called diorite, although many are so metamorphosed that no augite is present. This No. 237 is a very interesting dike of diorite porphyrite. It is very much faulted, and occurs at various points along the entire Lanesville shore. It has large crystals of feldspar, several inches in length, finely striated and very iridescent, hence probably labradorite. The feldspar is extremely decomposed to kaolin, muscovite, calcite, etc. Secondary green hornblende and biotite occur along the cracks in the feldspar and in bunches throughout the mass.[1] The rock is undoubtedly very much altered from its original state, and a careful study of it will be made and reported upon later.

There is considerable quartz and feldspar porphyry among the Cape Ann dikes. Nos. 3, 53, 127, 135, 147, 182, and 184 are of this character. No. 3 has porphyritic crystals of plagioclase and orthoclase feldspar and rounded quartz considerably resorbed. The ground mass is microgranitic, mainly quartz, feldspar, and hornblende, mostly the very pleochroic blue variety glaucophane, which gives a decided blue color to the rock. No. 53 has porphyritic crystals of feldspar with distinct outlines, but somewhat decomposed. The

ground mass is a confused aggregation of vesicular needles of brown hornblende, with clear spaces quite granophyric. This appearance may be primary, but it gives one the impression of felsite with a glassy or microfelsitic base altered to this condition.

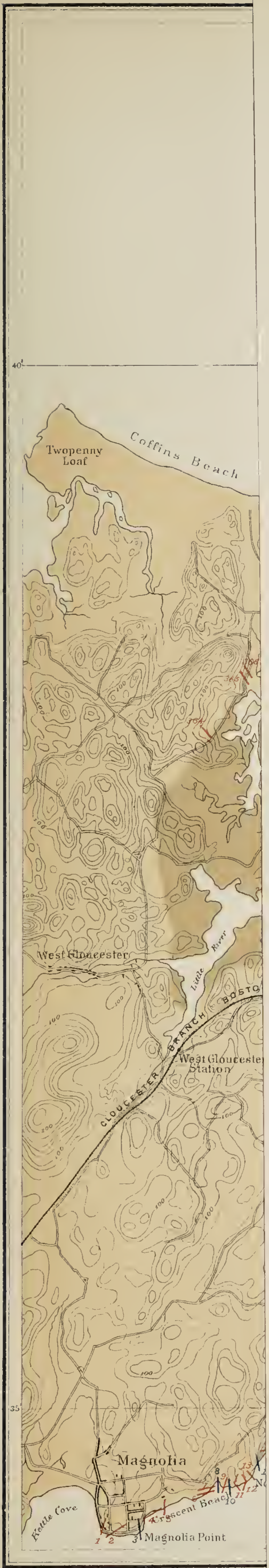
Nos. 127 and 135 are more typical quartz and feldspar porphyries. They occur as faulted and very irregular dikes, in some places, as at 127, looking like chimneys cutting the granite. Wherever a contact has been observed between the diabase dikes and quartz porphyries, the latter are found to be the older, and their ragged outline would indicate that they cut the granite before the joint planes were formed, for they never follow any system of joints and are often faulted along the line of joint planes. These dikes have the usual character of quartz porphyry. Embayed porphyritic crystals of quartz and feldspar exist in a ground mass of quartz, feldspar, hornblende, and biotite. In the center the ground mass is quite holocrystalline, but at the contact it becomes cryptocrystalline. No glass or microfelsite is found, although the structure leads one to suspect that these conditions once existed, and that the present structure is the result of devitrification.

Nos. 182 and 184 are narrow schistose dikes, apparently very much altered. They are fine grained, and composed of a mass of undecomposed feldspar, quartz, and blue hornblende—glaucophane. The rock shows signs of flow structure, and might be a gneissoid rock as well as a feldspar porphyry, but in places it has indistinct porphyritic feldspar crystals. The field evidence shows that they are dike rocks and the crystals look like porphyritic feldspars rather than crystals of secondary origin. Dike 135 has the quartz crystals very much faulted, and the cracks filled with the ground mass. In one place the graphic granite structure shows. The extensive cracking of the quartz grains seems to show that it has undergone some of the movements which have jointed the granite. The joints, too, are not all such as can be explained by cooling alone.

No. 147, on Thatcher's Island, is an interesting dike of quartz porphyry, which shows a beautiful spherulitic structure. It has a cryptocrystalline ground mass of quartz and feldspar with porphyritic crystals of the same. A more thorough petrographic study will be made of some of these dikes, the object in this report being simply to indicate their general character.

## INFLUENCE OF GEOLOGICAL STRUCTURE UPON THE HEALTH OF THE DISTRICT.

Although the general position of Cape Ann should be favorable to the health of its inhabitants, the vital and sanitary statistics show that the area suffers from certain classes of maladies, known as zymotic diseases. It is probable that these evils are caused in part at least by the failure to recognize the important fact that the soil of


Twopenny Loaf
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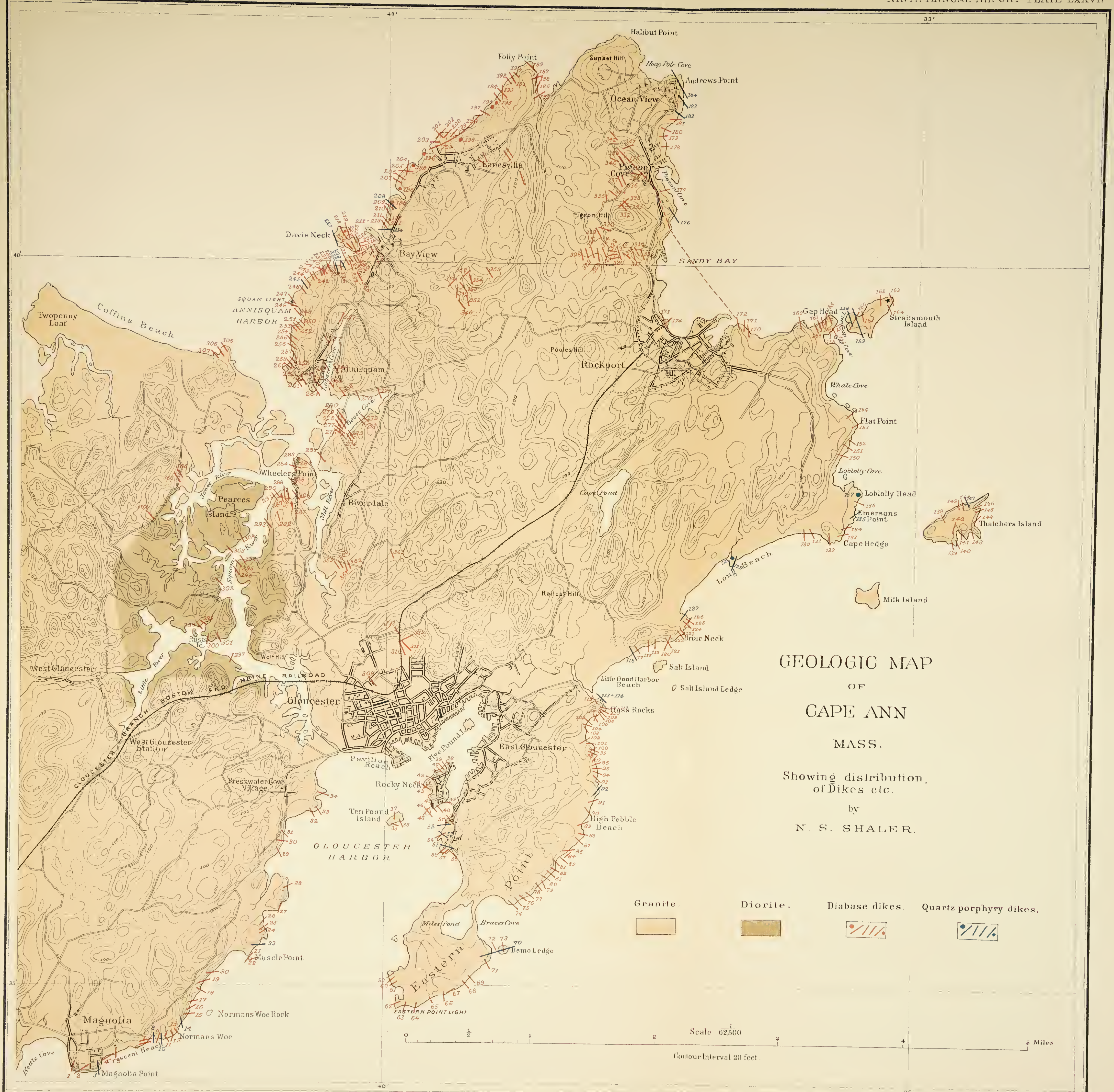
Magnolia
Kettle Cove
Magnolia Point


GEOLOGIC MAP
OF
CAPE ANN
MASS.
Showing distribution of Dikes etc.
by
N. S. SHALER.
Granite.
Diorite.
Diabase dikes.
Quartz porphyry dikes.
Scale 1/62,500
0 1/2 1 2 3 4 5 Miles
Contour Interval 20 feet.
Halibut Point
Folly Point
Sunset Hill
Hoop Pole Cove
Andrews Point
Ocean View
Lanesville
Pigeon Cove
Pigeon Hill
Davis Neck
Bay View
SANDY BAY
SQUAM LIGHT
ANNISQUAM HARBOR
Twopenny Loaf
Coffins Beach
Annisquam
Pooles Hill
Rockport
Gap Head
Straitsmouth Island
Whale Cove
Flat Point
Loblolly Cove
Loblolly Head
Emersons Point
Cape Hedge
Thatchers Island
Long Beach
Milk Island
Cape Pond
Wheelers Point
Pearces Island
Riverdale
Mill River
Railcut Hill
Briar Neck
Salt Island
Salt Island Ledge
Little Good Harbor Beach
Bass Rocks
West Gloucester
Wolf Hill
BOSTON AND MAINE RAILROAD
GLOUCESTER BRANCH
Gloucester
West Gloucester Station
East Gloucester
Pavilion Beach
Five Pound Id.
Rocky Neck
Freshwater Cove Village
Ten Pound Island
GLOUCESTER HARBOR
High Pebble Beach
Eastern Point
Miles Pond
Braces Cove
Bemo Ledge
EASTERN POINT LIGHT
Muscle Point
Normans Woe Rock
Normans Woe
Magnolia
Kettle Cove
Crescent Beach
Magnolia Point

this peninsula is of a peculiar character. Almost all the other coast towns of New England are in the main underlain by permeable drift, kames, or other detritus, containing little or no clay. As will be seen from the map, nearly the whole of Gloucester and Rockport rest upon till. Even where there are materials affording ready passage to ground water, the bed rocks are often very near the surface and thus the sewage is unable to penetrate to any great depth and becomes mixed with the water of the wells. At least three-fourths of the sources of domestic water supply on the Cape from wells and springs are liable to contamination. I know no other equal area in Massachusetts where the sources of potable waters are in general so objectionable as in these two towns of Gloucester and Rockport. Recently the city of Gloucester has provided itself with a system of water supply drawn from a tolerably satisfactory source west of Annisquam River; but a large part of the water in that city is still obtained from wells, and the villages of Rockport, Pigeon Cove, Lanesville, Bay View, and Annisquam are dependent on such sources of supply.

It will be easy to remedy these difficulties at a relatively small cost. The unsettled region of the great moraines, the section commonly known as "Dogtown Commons," contains an area of several square miles of land which at present has very little value. A thousand acres of this land in the center of the island should be reserved for water supply. This morainal matter is so permeable to water that wells of no great depth placed in the center of such a reservation would afford a sufficiency to supply all the settlements along the coast line. This water would be obtained at such a height that the costs of pumping would be small. The land for such a source of supply could probably be obtained at the present time at a small cost, and the maximum distance from the source to the furthest of the shore settlements would not exceed three miles. An incidental advantage arising from such a reservation would be found in the fact that it might in time be made a park of value to all the settlements on this island.

# FORMATION OF TRAVERTINE AND SILICEOUS SINTER BY THE VEGETATION OF HOT SPRINGS.

BY

WALTER HARVEY WEED.

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# FORMATION OF TRAVERTINE AND SILICEOUS SINTER BY THE VEGETATION OF HOT SPRINGS.

By Walter Harvey Weed.

## INTRODUCTION.

Among the many interesting natural phenomena that claim the attention of the visitor to the Yellowstone National Park, the geysers and hot springs rank first in general interest. Their novelty and beauty are sure to attract universal admiration, while the vast quantities of hot water that flow from the ground are convincing evidences of the nearness of internal heat. These steaming fountains and boiling pools are usually surrounded by snowy white borders of mineral matter deposited by the hot waters. At the Mammoth Hot Springs this consists of carbonate of lime, that forms the unique marble terraces and pulpit basins of those springs. (Pl. LXXIX.) At the Geyser basins the waters deposit silica, that forms the fretted rims of the pools and the beautifully beaded and coral-like deposits of the cones, and covers large areas of ground about the springs with a sheet of white and glaring sinter. Not only are the occurrence and the nature of these deposits such as make them of interest to every visitor, but the problem of their origin has proved to be one of the prominent features in the scientific investigation of the hydrothermal phenomena of the park, as it has been found that such deposits are very largely due to the growth and life of a brilliant colored algous vegetation, living in the hot mineral waters.

## PLANTS AS ROCK-BUILDERS.

A review of the various geologic agents that have built up the strata forming the earth's crust shows that living organisms have taken an important part in rock formation. The abundance of their remains in ancient as well as the most recently formed sediments shows that the corals and mollusks of all periods have been active rock-builders. The geological work executed by such forms of animal life is therefore quite apparent to the students of nature. On the contrary, the geological work of plant life has not been generally recognized, partly because it is less conspicuous, and partly because the absence of organic remains in many deposits formed in this way has prevented a recognition of the true origin of the rocks.

It has been proved that living plants further geologic change in several ways; by promoting the disintegration and decay of existing rocks, by building up new rock formations, and, upon their death, by starting a series of changes resulting from the action of the decaying vegetable matter upon various mineral substances. New formations are built up by living plants in two ways—by the accumulation of their plant remains and by the chemical reactions resulting from the growth and life of the plants: in either case mineral matter is deposited. Where the mineral matter preserves the form and structure of the plant, as is the case with the silica forming the well-known beds of diatomaceous earth, the origin of the deposit is apparent, but in many cases no trace of plant structures can be distinguished, even when thin sections of rocks that are undoubtedly formed by plants are seen under the microscope. This is true of some marine limestones formed by calcareous algæ, and is especially true of several classes of deposits heretofore considered to have a purely chemical origin, such as travertine, siliceous sinter, certain gypsums and iron ores. In such cases it is only by a careful study of the actual process of formation of the deposits that we can tell with certainty their true manner of formation. This has been done in the case of the deposits formed about the hot springs and geysers of the Yellowstone Park, and it is the purpose of the present paper to show the origin and manner of formation of these interesting mineral deposits.

## VEGETATION OF HOT WATERS.

The presence of organic life in highly heated mineral waters is a subject of considerable interest not only to students of biology, but to geological observers as well. It shows the development of life under very adverse conditions of temperature, and affords an opportunity for the study of the modifying effect of high temperatures and chemical solutions upon forms found also in ordinary surface waters. The ability of life to withstand such extreme conditions shows the possible existence of such forms in the early history of the earth, when the crust is supposed to have been covered by highly heated mineralized water. Thus far this subject has received but little attention, and the data accessible are meager and unsatisfactory, this being especially true of the animal life of hot waters.

The vegetation of hot springs consists entirely of various species of fresh water algæ, flowerless cryptogamic plants, closely related to the salt water algæ or sea-weeds. The fresh water species are less striking and varied than the marine growths, and are generally composed of green thread-like structures of more or less slimy consistency.[1]. It is well known that algæ are abundant in the hot waters of many and widely separated localities, for, in the various works of

[1] Phycology: Prof. Farlow, in Johnson's Encyclopedia.

travel and exploration in which the occurrence of hot springs has been described, mention is frequently made of bright green confervæ living in the hot pools and streams. Where the plants present in thermal waters are of this color their vegetable nature seems to have been readily recognized, but there is reason to believe that the existence of algæ of other colors, such as the red and yellow species common in the Yellowstone springs, has generally been overlooked or the growth mistaken for mineral matter. This is not surprising, as the plants are often incrusted and hidden by mineral material deposited by the hot water, and the organic nature of the substance is often scarcely recognizable even by botanists. Thus in sulphur waters the algæ are very generally incrusted by grains of sulphur, or are inclosed in gypsum, while the vegetation of calcareous springs is often buried in travertine deposited by the water, only the growing tips of the plants being free. Similarly, the threads of algæ living in ferruginous waters are incrusted by oxide of iron, while in siliceous waters such growths are inclosed in gelatinous silica.

In reviewing the literature of this subject, vegetation is found to be a common accompaniment of thermal springs in all parts of the world, but, although the presence of these hot-water growths has been recognized, the conditions under which they exist are rarely given and the plants themselves have been studied and identified at very few localities. Of these the foremost is Carlsbad, Bohemia. Its hot springs have long been noted for their curative properties, and thus they attracted the attention of scientific men at an early date. In 1827, Agardth described the algous growths of these thermal waters,[1] and the botanist Corda[2] figured and described species from these springs in 1835. Schwabe published a paper in 1837[3] in which he describes the occurrence of the algæ, giving the temperatures at which the different species were found, besides figuring and describing the plants themselves. The most important paper, from a geological stand-point, is, however, that published by Prof. Ferd. Cohn in 1862,[4] in which the physiological action of the plant life is shown to cause the deposition of travertine by the hot waters.

Algæ from the hot springs of Italy were described by Meneghine[5] in 1842, and Ehrenberg says[6] that algæ occur in the hot springs of Ischia at 174° F. to 185° F. Hoppe Seyler[7] found similar vegetation in the hot waters of Lipari at 127° F. The writings of Kützing mention a number of species from European hot springs, and other localities are given by Rubenhart.[8]

The hot springs and geysers of Iceland have been famous for many centuries, but a careful examination of the writings of the

[1] Flora, 1827.
[2] Almanach de Carlsbad, 1835–'36.
[3] Linnæa, 1837.
[4] Abhandl. Schles. Gesell. Naturwiss., Heft 2, 1862.
[5] Monographia Nostochinarum Italicarum: Turin, 1842.
[6] Sachs in Flora, 1864.
[7] Pflugers Archiv, 1875.
[8] Flora Aquæ Dalcis.

numerous travelers who have visited and described them shows that only three authors have mentioned the presence of algous vegetation in the hot waters. Sir William Hooker,[1] who visited Iceland in 1809, found confervæ at the borders of many of the hot springs, where the plants were exposed to the steam and heat of the boiling water. *Confervæ limosa* Dillw. was found in abundance, forming large dark-green patches attached to a coarse white clay, from which it could be easily peeled off. A brick-red confervæ, an *Oscillatoria*, occurred in a similar way, forming large patches several inches square. *Confervæ flavescens* Roth, and a species allied to *C. rivularis*, were abundant in water of a very great degree of heat.

Baring-Gould, who visited the geysers in 1864, found a crimson algæ growing in the spray and overflow of the spring Tunguhver.[2] He collected specimens, which were examined by Rev. J. M. Berkley, who referred them to the genus *Hypheothrix*, common in hot waters all over the world. Lauder Lindsay found two kinds of confervæ in the springs of Laugarnes, Iceland, in water so hot that an egg was boiled in it in four to five minutes.[3]

In New Zealand the presence of algæ in the hot springs on the south shore of Lake Taupo was first noted by Hochstetter, who says[4] the dark emerald-green growth covered the ground where the warm water flowed. The specimens collected by him are described in the Botany of the Novara Expedition.

Algæ from these springs are also described by W. I. Spenser,[5] the highest temperature of the water in which they were found being 136° F. Hochstetter says the temperature of the springs varies between 125° F. and 153° F.

Dr. S. Berggren, of Lund, Sweden, visited the hot spring district of New Zealand in 1874, and collected an extensive series of specimens of the algæ of the region. He states[6] that the algæ, especially *Phycochromaceæ*, but likewise *Confervaceæ* and *Zygnemaceæ*, are to be found growing in great abundance in the rivulets from the hot springs.

These specimens have been studied by Dr. Otto Nordstedt, whose determinations show that the species are chiefly those common in hot waters in other parts of the world, and that several species occur both in hot and cold waters.

Thick masses of slimy confervoid plants line the bottom of a large pool, Tapui Te Koutu, at Rotorua, New Zealand, where the usual temperature is 90° to 100° F., but is 180° with a north or east wind.[7]

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[1] Journal of a Tour in Iceland, vol. 1, p. 160.

[2] Iceland: Its Scenes and Sagas.

[3] Bot. Zeitung, 1861, p. 359.

[4] Reise der Oe. Frègatta Novara: Geol., vol. 1, pt. 1, p. 126.

[5] Trans. New Zealand Inst., vol. 15, p. 302.

[6] Kongl. Sv. Vet. Akadèmiens Handlingar, Band 22, no. 8, p. 5.

[7] Skey. Mineral Waters of New Zealand · Trans. New Zealand Inst., vol. 10, p. 433.

At the Azores, Mr. Mosely, naturalist on the *Challenger* expedition, found algæ growing about the hot springs of Furnas Lake, island of St. Michael.[1] The algæ occur on areas splashed by the hot sulphurous waters, forming a pale, yellowish-green layer an inch and a half thick. The color is most intense in the inner layers of the growth. This gelatinous vegetable matter occurs mingled with a gray earthy material in successive layers. The temperature of the water was 176° F. to 194° F. A thick brilliant green deposit, consisting of *Chroococcus*, was found at the edge of a shallow pool of hot water whose temperature was between 149° F. and 156° F. Specimens were also collected from a swamp of hot mud in which, beside algæ, a rush (*Juncus*) was found growing. The temperatures given by Mr. Mosely are all estimated, but are probably correct within the limits stated. The specimens obtained from these springs were examined by Mr. W. Archer, and the result of his study published in a paper[2] which is mainly botanical, but is interesting in this connection as showing the identity of many of the species from the hot waters of the Azores, with species common in the cold waters of Great Britain.

In the narrative of the voyage of the *Challenger*, Mr. Mosely describes the occurrence of similar hot-water growths at the Banda Islands and at the new volcano of Camiguin. At the first locality gelatinous masses of algæ resembling those growing in the Azores hot springs were found around the mouths of fissures from which jets of steam issued, the only water present being that supplied by the condensation of the vapor. This sulphurous steam had a temperature of 250° F. within the fissure, and the thermometer stood at 140° where the algæ flourished. In some places the algæ and a white mineral incrustation formed alternating layers.[3]

At the base of the new volcano of Camiguin two hot streams were full of algæ. No vegetation was found in hot water where the temperature exceeded 145°.2 F., but in the stream-bed green patches occurred on stones projecting above the surface. As the water of this stream became cooler, a few yards farther down, algæ were found growing in the middle of the channel at 113°.5 F. "This," says Mr. Mosely, "seems to be the limiting temperature for this particular algæ in this water." Where the temperature of the stream was 122° F. it fed a little side pool where algæ were growing at a temperature of 101°.5 F.[4]

Dr. Hooker found algæ in the hot springs of the Himalayas at several localities.[1] At Soorujkoond or Belcuppec (in the Behar Hills)

[1] Journ. Linn. Soc. (Bot.), vol. 14, 1875, p. 321.

[2] Ibid., p. 328.

[3] Voyage of H. M. S. *Challenger:* Narr., vol. 1, part I, p. 563.

[4] Ibid, p. 654.

brown and green algæ were found forming broad, luxuriant strata where the temperature did not exceed 168° F., the growth thriving until the water had cooled down to 90° F. The brown algæ were found in deeper and hotter water than the green. In an appendix, Rev. J. M. Berkley, writing about the specimens collected from these springs, says a *Leptothrix* occurs from 80° F. to 158° F., an imperfect *Zygnema* between 84° F. and 112° F.[2] The same writer also describes specimens collected by Dr. Hooker from the hot springs of Momay at 110° F., and from Pugha, Thibet, in springs having a temperature of 174° F.[3]

Green algous growths were observed by Prof. J. D. Dana in the hot springs of Luzon at 160° F.,[4] and similar vegetation was found in the Celebes hot springs in waters of 123°.8 F. and 170° F. by Prof. A. S. Bickmore.[5] Green algous vegetation was also noted in many Japanese hot springs by Benj. Smith Lyman.[6] Cushion-shaped masses of slippery gelatinous vegetation—*Oscillatoria labyrinthiformis* Ach.—were found by Junghuhn in the hot springs of Java[7] at 150° F., and a species of *Oscillaria* was found associated with a milk white precipitate of *sulphate* of lime at Tji-Panas.

In the United States algæ have been found in hot springs at many localities. Red, white, and green growths occurring in the warm sulphur springs of Virginia have given rise to the names of many of these famous resorts.[8] At the hot springs of Arkansas green cryptogamic vegetation occurs in water having a temperature of 140° F., and a species from this place is described by Kützing.[9]

At the so-called "geysers" of Pluton Creek, California, green algæ occur in the hot acid water in great abundance. Prof. W. H. Brewer found that the highest temperature noted at which the plants were growing was 200° F., but they were most abundant in waters of 125° F. to 140° F. The growth in the hottest waters was apparently of the simplest kind, and composed of simple bright-green cells. Where the water had cooled to 140° F. to 149° F., bright-green filamentous confervæ formed in considerable masses. Similar growths formed coatings on the soil about steam-jets, and were alternately exposed to very hot steam and cooler air. In a specimen collected from water having a temperature of 130° F., Mr. A. M. Edwards, of

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[1] Himalayan Travels: Jos. Dalton Hooker, vol. 1, pp. 27, 379.

[2] The temperatures given by Mr. Berkley are 10° lower than those given by Hooker.

[3] Loc. cit., p. 379.

[4] Manual of Geology, by Jas. D. Dana: 3d ed., 1880, p. 612.

[5] Travels in East Indian Archipelago.

[6] Prelim. Reports, Geol. Surv., Japan, 1874, 1877, 1879.

[7] Java, Seine Gestalt, Fr. Junghuhn: vol. 2, pp. 864, 866, 868, 870, 873.

[8] Geology of the Virginias, W. B. Rogers, pp. 107, 589.

[9] Species Algarum.

New York, is said to have found animal as well as vegetable organisms. Professor Brewer also states that in the hot siliceous waters of Steam-boat Springs, Nevada, there is an abundant confervoid vegetation in the gelatinous mass formed where the water spreads out over the surface. This was most plentiful where the temperature was about 100° F. The most interesting feature of this occurrence is the abundant vegetation in the gelatinous silica.[1] Mr. James Blake found diatoms in water having a temperature of 163° F. at the Pueblo Hot Springs, Nevada.[2] The algæ growing in the Benton Spring, Owen's Valley, California, are described by Mrs. Partz as representing three forms. The first is developed in the basin of the spring at a temperature of 124° F. to 135° F., the temperature of the water at the point of issue being 160° F. In the warm creek formed by the overflow of the spring the algæ form waving fibers two feet long, at temperatures between 110° F. and 120° F. Below 100° F. these plants cease to grow, but a bright-green, slimy fungus occurs, disappearing as the temperature decreases. Dr. H. C. Wood gives technical descriptions of these plants,[3] and says the forms develope at the highest temperatures are immature. The presence of green confervoid vegetation in many other hot springs has been noted by various writers, but no description has been given either of the plants themselves or of the temperature and other conditions governing their occurrence.

In the hot springs of the Yellowstone National Park no plant life has been found at a temperature exceeding 185° F., but at temperatures between 90° F. and 185° F. algous growths are generally present. In the reports of the Hayden Survey for 1871 and 1872 there are several references to the presence of vegetation in the hot waters. At the Mammoth Hot Springs, Dr. F. V. Hayden observed the occurrence of pale yellow filaments about the springs and the green confervoid vegetation of the waters, as well as the presence of diatoms in the basins of the main springs, two species of the latter, *Palmella* and *Oscillaria*, being recognized by D. Billings.[4] Green vegetation was also noted in the hot waters of the Washburne, Pelican, and Terrace Springs, and at the Lower Geyser Basin.[5] The brown leathery lining of the springs of the Lower Geyser Basin of the Firehole River was thought by Dr. Hayden to be an aggregation of diatoms covered with iron oxide.[6] In 1872 Prof. F. H. Bradley recognized the presence of vegetation in the hot springs of the park, and writing of the hot waters of the Geyser Basins, says

[1] Amer. Jour. Sci., 2d series, vol. 41, p. 391.
[2] Manual of Geology, by James D. Dana, 3d ed., 1880, p. 611.
[3] Amer. Jour. Sci., 2d series, vol. 46, p. 31.
[4] Ann. Rept. U. S. Geol. and Geogr. Survey of the Territories for 1871, pp. 69,70.
[5] Loc. cit., p. 136, and 1872 report, p. 55.
[6] Loc. cit., 1871; p. 105.

that there are gelatinous forms allied to mycelium, or mother of vinegar, in nearly all the pools, except where the ebullition is so strong as to break up such tender tissues. This material occurred in broad, thick sheets of green or rusty brown, in thick, branching forms, resembling sponges, or in long waving white fibers.[1] In the mucilaginous deposit on the side of a spring at the Lower Geyser Basin Dr. Josiah Curtis found skeletons of diatoms, but no living ones. Professor Bradley said the colors striping the mound of the Solitary (Lone Star) Geyser are due to purely vegetable material. His assistant, Mr. Taggart, reported leafy vegetation in springs of 120° or less at Lewis Lake, where the springs of higher temperature contained pulpy masses of a fungoid growth common about the hot springs of the Geyser Basins.[2] The botanist of the expedition, Prof. John Coulter, says in his report that algæ were discovered growing in some of the hot springs. He collected orange-colored confervoid specimens from the waters of the Lower Geyser Basin which were identified by Charles H. Peck as *Confervœ aurantica.*[3] Prof. Theodore Comstock, who visited the park with the Jones expedition in 1873, records the presence of green confervæ in the Green Spring, Pelican Creek, at 104° F., and similar growths were found at Turbid Lake, Mammoth Hot Springs, Excelsior Geyser, Sapphire Springs, and the Lake Shore Hot Springs.[4] The same observer noticed the silken yellow filaments at the Mammoth Hot Springs, and supposed the abundant "colloid matter" of the springs to originate from organic matter contained in the water, the forms being produced by the rising or buoyancy of bubbles of carbonic acid gas.[5] Dr. C. C. Parry, botanist of this expedition, noticed the presence of algæ in the hot springs of the park, and says they will reward special research.[6]

The report of Dr. A. C. Peale upon the thermal springs of the Yellowstone National Park[7] contains but little about the vegetation of the Park hot springs. Under the heading, "Life in Hot Springs," he says:

> At numerous places in all the geyser areas and at Gardiner's River masses of gelatinous material of greenish-red, yellow, and brown colors are noticed, and usually have been considered of organic origin. In most cases where microscopical examination has been made no trace of vegetable organization has been noted, and in regions where the springs are siliceous this curious material is probably that form of gelatinous silica described in another place as viandite. In some springs of very low temperature a brown, leathery-looking material is found lining the basins. It

[1] Ann. Rept. U. S. Geol. and Geog. Survey of the Territories for 1872, pp. 207, 231.

[2] Loc. cit., 1872, p. 250.

[3] Loc. cit., p. 752.

[4] Report of Reconn. N.W. Wyoming in 1873, by Capt. Wm. Jones, U. S. War Dept., pp. 190, 194, 210, 228, 231, 238.

[5] Loc. cit., p. 207.

[6] Amer. Naturalist, 1874, p. 178.

[7] Final Rept. U. S. Geol. and Geog. Survey Terr., 1878, vol. 2, p. 359.

becomes hard upon drying, but has not as yet been examined microscopically or chemically, so that its nature is unknown, but in all probability it is one of the forms of silica rather than an organic material.

This evidently represents the views of Dr. Peale and his colleagues regarding the nature of the algous growths of the Park hot springs at the time this report was prepared.

This review of the literature of the subject shows how few occurrences of hot-spring vegetation have as yet been carefully observed and described. In the cases noted, naturalists have generally given the temperature of the water in which the plants were found, and the specimens collected have been studied from a purely botanical point of view, but with the notable exception of Prof. Ferd. Cohn, observers have entirely overlooked the geological work of the lowly organized plants and the part they take in the production of hot-spring deposits.

These hot-water growths, like all fresh-water algæ, are more widely distributed than any other plants save those peculiar to brackish waters. This is shown by the occurrence of algous vegetation in the hot springs of such widely separated localities as Iceland, the Azores, New Zealand, Japan, and the United States. A comparison of the species shows that the flora is very uniform in character, being limited to a few groups and the species themselves being identical to a great extent.

Perhaps the most interesting feature connected with the life of these algæ is their tolerance of a high degree of heat. The extreme temperature at which vegetation has been observed is 200° F., recorded by Prof. W. H. Brewer at the California "Geysers." On the island of Ischia, near Naples, no algæ were found in hot waters above 185° F., which accords with the observations made in the Yellowstone National Park. At other places these growths have not been found at such high temperatures. Dr. J. D. Hooker found the limit to be 168° F. in the Himalayan springs, and Prof. Ferd. Cohn says no growths are present in the Carlsbad waters, where the temperature exceeds 44° R. (131° F.). As regards the effect of the chemical substances dissolved in the water there is but little known, but vegetation has been found in all varieties of water, sulphurous, calcareous, acid, and alkaline, and so far as observed the amount of material held in solution does not affect the growth. Certain species, however, are known to be peculiar to particular waters. Thus the *Beggiatoœ* form the characteristic vegetation of sulphur springs, and *Gaillionœ* are found in iron-bearing waters. The adaptability of particular algæ to extreme conditions of environment is shown by the occurrence of the same species in the highly heated sulphurous-siliceous waters of the Azores and the cold surface waters of Great Britain.

Altitude is not known to affect the growths, and algæ are found

in Iceland but a few hundred feet above sea level, in the Yellowstone National Park at 7,500 feet, and in the Himalayas at an elevation of 17,000 feet.

## HOT SPRINGS OF THE YELLOWSTONE NATIONAL PARK.

Regions of solfataric activity have always been of peculiar interest to scientific observers, not only on account of the curious and often extremely beautiful hot springs and the rarer occurrence of geysers in such districts, but also from the varied phenomena of rock decomposition and of mineral formation and deposition which always accompany such hydrothermal action. It is in these natural laboratories that we are permitted to see in operation processes which have produced important changes in the rocks of the earth's crust and afford a key to many of the problems of chemical geology.

There is perhaps no other district in the world where hydrothermal action is as prominent or as extensive as it is in the Yellowstone National Park. In this area of about 3,500 square miles, over 3,600 hot springs and 100 geysers have been visited and their features noted, and there are also almost innumerable steam vents. With few exceptions the hot waters are siliceous, and rise through the acidic lavas of the park, and it is probable that it is owing to this fact that the deposits formed by the hot waters do not differ more in character. The facts upon which this paper is based have been obtained in the course of a series of comparative observations carried on by the writer for the past six years at the different hot-spring areas of the Park, under the direction of Mr. Arnold Hague, geologist in charge of the Geological Survey of the Yellowstone National Park.

## THE MAMMOTH HOT SPRINGS.

Although the Yellowstone Park abounds in hot springs, calcareous hot waters are extremely rare, and but one locality is known where such springs have formed deposits of travertine, or calcareous tufa, of any considerable extent. This is the Mammoth Hot Springs. At this place the heated waters rising through Mesozoic limestone reach the surface heavily charged with carbonate of lime in solution, which is deposited by the hot waters in the form of travertine, affording an excellent opportunity for a study of the formation of this mineral.

Calcareous hot waters are not rare in nature, but are found in many parts of the world, and are usually surrounded by deposits of travertine often of considerable extent; yet there are few places where such deposits equal those of the Mammoth Hot Springs in magnitude, and none exceeding them in beauty. The travertine deposits of Hierapolis in Asia Minor, famous for its hot waters in the time of the Emperor Constantine, form a white hill whose slopes are ornamented with basins resembling those of the Marble Terrace of the Mammoth Hot Springs, and the springs of the Hammon Meschoutin,

TERRACED BASINS OF BLUE SPRINGS, MAMMOTH HOT SPRINGS.

in Algeria, have built up cones and ridges which are the duplicate of those found on the terraces of our own locality.

### GEOLOGICAL RELATIONS.

The Mammoth Hot Springs form the most northern of the numerous hot-spring areas of the Park, being situated in the northwest corner of the reservation, three-quarters of a mile south of the forty-fifth parallel, which forms the Montana-Wyoming boundary. As it is but seven miles from the terminus of the railroad it forms the first stopping place of the traveler who enters the Park from the north, and it is the most accessible of the many points of interest in this region. The situation is extremely picturesque; the dark and lofty summit of Sepulchre Mountain rising near by on the north, while the upper valley of the Yellowstone and the sharp peaks of the Snowy Range are seen at the northeast, between the slopes of Sepulchre and the long mural face of Mount Evarts. In the southeast the eye dwells pleasingly upon the distant view of the ravine of Lava Creek and Undine Falls, with many snow-flecked peaks in the far distance. Bunsen Peak rises abruptly in the south, its dark slopes forming a pleasing background to the white mass of hot-spring deposit when seen from the north. This deposit fills an ancient ravine lying between Terrace Mountain and Sentinel Butte, the grassy slopes of the latter showing exposures of Jurassic and Cretaceous limestones carved into well-defined benches by glacial action. Immediately south of the travertine terraces the sedimentary strata are covered by rhyolite, the northern extension of the great lava flows which fill the ancient basin of the Park. Near the Gardiner River, Cretaceous sandstones form small ridges, dividing the travertine sheet into three tongues; these beds dip steeply eastward, passing beneath the strata forming the face of Mount Evarts.

### TRAVERTINE DEPOSITS.

The total area covered by the travertine is about two square miles, including the beds of preglacial age which form the summit of Terrace Mountain. The greatest thickness is probably about two hundred and fifty feet, but the average is very much less. The upper limit of the deposit, forming the terraces and filling the ravine, is about 1,400 feet above the Gardiner River and 7,100 feet above sea level; the travertine extends from this terrace down to the river, forming a continuous covering of varying width and thickness. It is impossible to measure the volume of the deposit as the thickness is variable, and the contour of the underlying surface can be conjectured only by the relation of the neighboring slopes.

The usual approach to the Mammoth Hot Springs from the railroad is over the road leading up the picturesque gorge of the Gardiner to the foot of the terraces. Recrossing this stream near its

junction with the Hot River, the road gradually ascends to the flat or terrace on which the hotels stand, 500 feet above the river. The road is built upon the hot-spring deposit, hidden on the lower slopes by drift and soil but exposed during the last 200 feet of the ascent, where many well-preserved basins may be seen on the pine and cedar covered slopes.

When first seen the main mass of the recent deposit is striking from its whiteness, resembling an immense snow-bank, filling a narrow valley whose pine-clad sides are in strong contrast to the white travertine. It has been compared by Prof. Arch. Geikie to the terminal front of a glacier, and by other writers to a foaming cascade suddenly turned into stone. Streaks and patches of red, yellow, and green seen upon these white slopes mark the course of the overflowing waters, and clouds of steam float lightly upward from the springs of the main terrace and vanish in mid-air. There are in all eight well-defined benches or terraces formed by the travertine, each with a more or less level surface, and terminated by steep slopes leading to the terrace below. The largest of these flats is the Hotel terrace, which is 83 acres in extent. This possesses several features of interest. These are usually overlooked in the desire to see the greater wonders and beauties of the upper terraces, but one can scarcely fail to notice the Liberty Cap, a pillar 43 feet in height with sphinx-like profile, the cone of a hot spring long extinct. This cone and its companion, the Thumb, with the immense empty hot-spring bowls of this terrace, attest an activity and size for these extinct springs far surpassing any now active.

## THE SPRINGS AND THEIR VEGETATION.

With the exception of the Hot River all the active springs now issue from the terraces above the hotels, or from the upper part of the hotel terrace itself. These seventy-five springs vary in temperature from 80° F. up to 165° F., and in size from small oozes of hot water to basins 50 by 100 feet across, with an overflow of many thousand gallons per hour. Algæ have been found in all these springs, and it is this vegetation, and the part which it takes in the formation of travertine by the hot waters, that are of especial interest in the present paper.

In wandering around the terraces of this great deposit of travertine the observer is sure to be impressed with the brightly tinted basins about the springs and the red and orange colors of the slopes overflowed by the hot waters. These colors are due to the presence of microscopic algæ, which are not easily recognizable in this deposit, owing to their covering of travertine. In the cooler springs and channels similar vegetation forms the bright green, orange, or brown membrane-like sheets or masses of jelly, without apparent vegetable structure.

The true nature of the silken yellow filaments found in the bowls and channels of even the hottest springs is more apparent, though the yellow color is due to sulphur incrusting the algæ threads. The intimate relation of these algous growths to the deposits of newly formed travertine suggests at once that the algæ are encrusted by the carbonate of lime, and so aid in the formation of the tufa. While this is probably true, the chief work of these plants is the separation from the water of the carbonate of lime, which they cause by their abstraction of carbonic acid. Owing to this action, a common function of vegetation, such growths are an important factor in the formation of travertine by the Mammoth Hot Springs waters.

## GENERAL OCCURRENCE OF THE ALGÆ.

The general occurrence of the algous vegetation will be best understood if a brief description of a few of the typical springs is given.

The largest springs now active are those of the Main Terrace. This is a fairly flat area of 8¾ acres in extent and 250 feet above the hotels. On the north the terrace ends in abrupt slopes, extending down to the bench below; on the east and southeast the descent is more gradual, extending down to the military quarters 175 feet below. Near the center of this terrace are the Blue Springs. These springs shift their position from year to year, the rapid deposition of travertine choking up the vents, causing the springs to seek other and easier outlets. In this case it often happens that the pressure of the accumulated gas fractures the deposit, and the water issues in a jet a foot or more in height. A rim of travertine is soon built up about the vent, forming a basin, into which the water, now relieved of the excess of pressure, issues quietly, though in considerable volume. The most beautiful of the Blue Springs is a pool 15 by 20 feet in extreme dimensions filled with pellucid water apparently in violent ebullition. The sides and bottom of the basin are formed of pure white travertine, while the varying depths cause the water to appear all shades of blue and green, from a deep peacock blue in the deeper parts of the bowl to the lightest of Nile greens in the shallower recesses. The water, issuing with a temperature of 165° F., contains a large amount of gas, which escapes at the surface of the pool, causing the water to rise in a low dome, variations in the amount of gas producing a pulsating movement, sending out waves which ripple across the water and curl over the shallow margin of the bowl. The overflow passes over and under large fan-shaped masses of fibrous white or yellow travertine (Fig. 52) into the uppermost of a series of basins irregularly arranged in tiers, a portion running in serpentine waterways built up of travertine. These natural aqueducts are often two or three feet high. In the center is a

shallow gutter too small to hold the volume of the stream, which overflows the sides and fills the basins along its course.

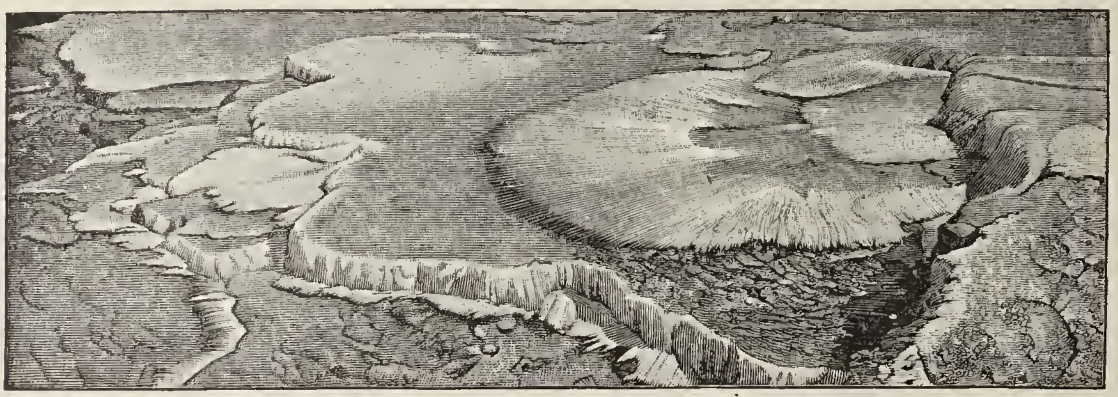

FIG. 52. Travertine fan, main terrace, Mammoth Hot Springs.

These terraced overflow basins form the most striking feature of the springs. No description can do justice to their beauty, for neither the delicate fretwork of their walls nor the frosted surface of the glistening deposit, nor the brilliant colors of the pools and rims can be described. Plate LXXVIII, from a photograph, shows a few of the many basins, of which each differs from the others. The walls are built up of pure white travertine, the surface resembling imbricated shells or a multitude of miniature basins, and often covered with a brightly colored vegetable jelly where the water is slightly cooled. These basin walls vary in height from a few inches to several feet. Their outline is rarely crescentic, usually irregular, wavy, and scalloped. The water runs over the rims in thin sheets and little cascades, depositing travertine wherever it flows and constantly building up the basins until the flow is checked by the increased height of the rims. Yellow sulphur-coated algæ threads are abundant in the bowl of the spring and the rapid-flowing streams, but the exquisite blues and greens of the hottest basins are due solely to the varying depths of water. The bright lemon, red, and green shades of the cooler pools are, however, entirely vegetable in their nature, and due to the presence of algæ lining the basins and striping their outer walls. In a general view of the entire collection of these basins, obtained from the edge of the terrace above, the effect is that of a brilliant mosaic, the colors occurring in well-defined areas outlined by the white travertine rims. As will be shown later, the contrasting tints of adjacent basins are due to the different temperature of the water and consequent different development of the algous vegetation. Looking at the pools near by proves that these colors are not pure, but are produced by a number of tints, minute differences in depth producing variations in color in the same basin. Large as is the overflow from the Blue Springs, little reaches the edge of the terrace, the water sinking into the porous deposit or flowing into holes and fissures in the travertine floor.

On the same terrace, but close to the southeastern edge, are the

MARBLE BASINS, MAMMOTH HOT SPRINGS.

two main springs. They are very much alike, and are to-day in nearly the same condition as in 1871, when they were first seen. The northern spring is a brown lined bowl, 75 by 100 feet across, and 5 to 8 feet deep. The flat margin is formed of smooth and polished salmon-colored travertine whose thin laminæ and hardness show it to have been quite slowly formed. The water is much cooler than that of the Blue Springs, having a temperature of 136° F. at the edge of the bowl. The supply is constant and issues from holes in the bottom of the basin, their location being distinguished by the lighter color of the water, the eddying currents, and an occasional stream of gas bubbles.

The perfect transparency of the water enables one to see the minutest details of the sides and bottom of the bowl. The volume of water which the two main springs pour out is not known, as the outflow does not run in definite channels, but pours over the eastern margins in a shallow sheet which, spreading out, flows down the rippled slopes and over the Marble Basins. Pl. LXXIX shows a few of the upper basins, which are often quite shallow, and hardly merit the name of basin. Here the waters deposit carbonate of lime rapidly, and the walls or basin-fronts are generally solid, while on the lower slope the cooled waters have parted with much of their lime, and deposit travertine slowly. On these lower slopes the basins are fringed with slender stalactites and pillars, forming the beautiful Pulpit Basins, illustrated in Pl. LXXX.[1] In this case, also, the pool or basin proper is very shallow, rarely a foot deep, and the rim or lip generally projects over the pillared front, as it is here that the deposition of travertine is most rapid.

Wherever the hot waters flow the deposit is brightly colored by the algous vegetation. The pools and basins near the springs are lined with deep red, while the slopes below are bright orange in color, and it is only near the base of the slope. where the waters are quite cool, that this color disappears.

## EFFECT OF ENVIRONMENT.

Algæ are abundant in all the springs and wherever the hot waters flow, but the growths vary in character and in color with the temperature of the water and with the situation in which they occur. If the temperature exceeds 150° F. a white filamentary alga is the only species present, the thread generally coated with sulphur; but where the water has cooled below that point, or issues with a lower temperature, a pale greenish-yellow growth is found, sparingly at first, but more abundantly and deeply tinted in cooler water, where it often entirely replaces the white species. This green alga is associated in turn with a red or orange species which gradually replaces

[1] Plates LXXVIII, LXXIX, and LXXX are engraved from photographs made by T. W. Ingersoll, of St. Paul, Minn.

it in the cooling waters, while in tepid streams too cool to support any of these forms an olive-brown species forms a soft, velvety covering over the travertine. Different conditions of flow and current produce varying forms of the same growth. In a rapid current the algæ are filamentary, while in quieter water the threads are united together in a membrane-like sheet or in masses of jelly, generally inflated by gas bubbles entangled in the vegetable tissue. At the borders of many channels the two forms pass into each other. Where the deposition of travertine is very rapid, as is generally the case on the overflow slopes and basin walls, the algæ are encased in the deposit and only the vegetating ends of the filaments are exposed and free.

The white algæ, which grow in the hotter waters, are generally coated with sulphur near the source of the spring, forming tufts of bright yellow filaments resembling skeins of silk, vibrating with the eddies and currents of the stream. Farther from the source these threads are not sulphur-coated, but are encrusted with carbonate of lime, and they form the radiating, fan-like masses of travertine shown in Fig. 52. The white algæ are generally found in the

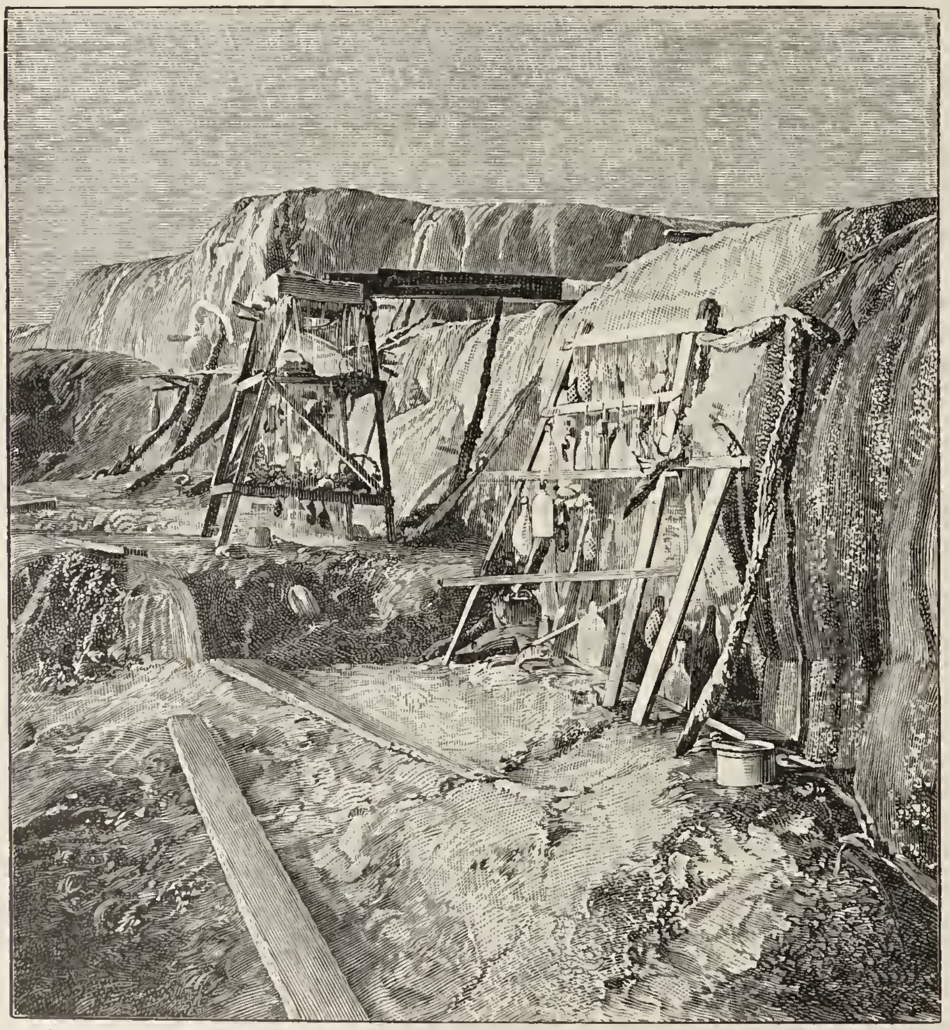

FIG. 53. Coating specimens, Mammoth Hot Springs.

rapid currents of overflow streams; rarely in the eddying waters of the hot-spring bowls.

It was suspected that this white or sulphur-coated species, so abundant in the hotter waters, might be identical with other and more brightly colored algæ, which had not been bleached by the hot sulphurous water. Specimens of a dark emerald-green growth were therefore placed in the overflow of a hot sulphur spring alongside of the white sulphur-coated filaments. In a few hours the green color had disappeared from the submerged portion of the green growth, and the white bleached filaments were partially coated with sulphur. Subsequent observations proved, however, that the white species maintains its character in comparatively cool waters, where it occurs associated with red and with green algæ, so that the experiment does not show the identity of the species, as was at first supposed. The green algæ are not such active travertine formers as the white and red species. They thrive best in the shade, or where hidden from the light by a covering of the red algæ, and the rich emerald-green color of the species changes to an olive or dull brown where exposed to direct sunlight. Flowing water seems to be necessary for its best development, so that, unlike the red algæ, the green species is seldom found on the bottom of overflow pools and basins. In water too hot for the full development of this alga, the growth is pale, yellowish green in color, or even bright yellow, frequently occurring in gelatinous masses showing no trace of filaments. In cooler water the color deepens to a rich emerald.

The orange or red algæ are very active in the formation of travertine, and there is not an overflow slope that does not show traces of its color. It tints the bottoms of the basins about the springs, and their rims and walls, with its varying shades of yellow, red, or brown, and it is this growth that imparts the tawny yellow or orange color to the slopes about all the springs, particularly noticeable on the slopes overflowed by the waters of the Main Spring. This species is rarely found free from lime, which generally incrusts it so thickly that it is difficult to distinguish its vegetable nature.

## DESCRIPTION OF THE VEGETABLE GROWTH.

The springs at the foot of the slope below the Pulpit Basins formerly presented the most luxuriant algous vegetation of the locality, in the area overflowed by their waters. This overflow is now chiefly used to supply the military stables, but formerly covered the flat north of the springs, flowing over a cushion of algous jelly several inches thick. The temperature of the spring was 127° F., and the channel near it was filled with a bubbly, gelatinous vegetation, emerald save at the edges, where it shaded into a dull, greenish brown. This changed gradually to a mixture of green and yellow where the temperature had fallen to 115°, but at 110° the surface of the jelly showed no trace of green, and the orange species only was seen, continuing abundant until at 97° F. the growth ceased. Traver-

tine deposition was taking place most rapidly where the temperature was 100° F., and the algæ were so heavily coated and inclosed by the deposit that its organic character was completely hidden, the light salmon-red color being apparently due to some mineral. It should be mentioned in this connection that these springs contain much less lime in solution than the other springs of this locality, and the waters do not coat and incrust articles placed in their spray. Only a small part of the overflow seems to have run over this salmon-colored crust, for upon tearing off this coating the inside is seen to consist of green algæ, the larger part of the overflow running through this vegetable conduit.

The association of the different species is well illustrated in their occurrence at the Orange Spring. This vent has built up a mound 15 feet high, 20 to 25 feet wide, and 50 feet long, with a gently arched summit and steeply sloping sides. The water issues from several little cones on the summit, situated along a line corresponding to the major axis of the mound, but there is usually one vent from which the greatest part of the overflow issues, and generally in a jet nearly a foot high. The temperature is but 148° F., so that this spouting is due to gaseous or to hydrostatic pressure. Falling into a little basin the water flows off in a ramifying network of little channels to the edge, where spreading out it forms a thin, glistening sheet, dashing and rippling down the steep slopes, only to sink in the porous travertine at the base of the mound. The water has a strong sulphurous odor, and the deposit about the vent contains considerable sulphur. If under water the surface of this deposit is black, with bunches of sulphur-coated filaments attached to the sides and bottom of the channel. Near the vent these are the only algæ present, but pale yellowish green threads are found in the cooler water at the border of the channel, and are abundant at 130° in many of the branch streamlets. As the water cools still more the green growth becomes deeper in color, and the red species appears at the edge of the stream. This growth is sometimes filamentary, but generally a jelly-like membrane, when not buried in the travertine. The surface of the mound between the reticulated channels is covered with a gelatinous coating of red and green algæ similar to those just mentioned, but mixed with crusts of carbonate of lime. Mushroom-shaped forms of salmon-colored travertine rise from the bed of the larger channels or project over the edges of the stream; these are formed partly by algæ and partly by evaporation.

The steep rounded or step-like slopes of the mound are bright orange in color where covered by the water, and it is undoubtedly this which gave the name to the spring. This coloring is due to algæ similar to those found on the summit of the mound, but the filaments are buried in the travertine, their tips alone projecting, reminding one of the growing points of peat mosses whose stems can

PULPIT BASINS, MAMMOTH HOT SPRINGS.

be followed down into the peat beneath. Where the overflow has become too cool to support the orange algæ, which does not live below 90° F., a brown species forms a smooth velvety coating on the travertine, and is very abundant at 85° F.; this in turn disappears as the water becomes still cooler.

In the overflow basins of the Blue Springs (Plate LXXVIII) the colors of adjoining pools are often quite different. In one of the hotter basins where the temperature was 142° the algæ tinting the deposit were a bright lemon yellow, while the rich, deep red growth of the adjoining basin lived at 115° F. The red growth is very prominent in water between 110° F. and 130° F. At the edge of a pool where the flow was comparatively quiet, a pistachio green growth merging into yellow and orange began at 145° F., the growth being thin and closely adherent. Close by a place where the flow was very sluggish, at a temperature of 130° F., the orange algæ are abundantly developed in gelatinous balloon-like forms. At 115° F. the red tint is much browner and at 95° F. is a dark orange brown.

In several of the basins, yellow, red, salmon, green, and brown interblend, owing to differences in depth and consequently in temperature and current. The vegetable nature of such growths is generally much obscured by the accompanying deposition of travertine.

## SOLUBILITY OF CARBONATE OF LIME IN NATURAL WATERS.

The large amount of carbonate of lime which the hot waters of the Mammoth Hot Springs contain in solution suggests an inquiry regarding the conditions under which such waters take that salt into solution.

In pure water the carbonate of lime is very sparingly soluble, the proportion given by Bineau being but one part in 30,000, to one in 50,000, or according to Fresenius, one part in 10,800 cold and 8,875 parts of boiling water. In carbonated waters the neutral carbonate of lime unites with the carbonic acid to form the bicarbonate of lime, which is readily dissolved in water to the extent of 0.88 grammes per litre in water saturated with carbonic acid gas at the ordinary atmospheric pressure and a temperature of 10° C. With an increase of pressure the amount taken into solution is augmented with the increase of carbonic acid absorbed, but the maximum amount that can be dissolved is about 3 grammes per litre.[1] The presence of alkaline and earthy salts in water free from carbonic acid favors the formation of unstable supersaturated solutions of carbonate of lime, from which the lime is gradually precipitated, this separation being more rapid from waters containing the chlorides than from those holding the sulphates of the alkalies and the alkaline earths. Magnesium sulphate and sodium sulphate form solutions with a certain amount of stability, but the lime is all precipitated in eight to ten days.[2]

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[1] Roscoe and Schorlemmer, vol. 2, p. 208.

[2] T. Sterry Hunt: Am. Jour. Sci., 2d series, vol. 42, p. 58.

In water saturated with carbonic acid the alkaline and earthy chlorides form unstable supersaturated solutions, from which the lime soon crystallizes out as the hydrous carbonate (at low temperatures) and the solution then contains but 0.8 grammes of carbonate of lime per litre, corresponding to that dissolved by the carbonic acid.[1] But the capacity of carbonated waters for carbonate of lime is nearly doubled by the presence of magnesium sulphate or sodium sulphate in the solution. Water holding either of these sulphates in solution in the proportion of $\frac{1}{100}$th or even less, and impregnated with carbonic acid, readily takes into permanent solution at the ordinary temperatures and pressure a quantity of pure carbonate of lime equal to 1.56 to 1.82 and even 2 grammes to the litre.[2] It is thus evident that solutions of carbonate of lime in pure or mineral waters are permanent only in the presence of free carbonic acid.

## CHARACTER OF THE HOT SPRING WATERS.

The water of the Mammoth Hot Springs is remarkably clear and transparent; the temperature varies at different springs from 80° F. up to 165° F., exceeding 130° in all the larger springs. While hot it generally possesses a sulphurous odor, the intensity varying greatly at different springs, but always being strong if the temperature exceeds 140°, when sulphur is found incrusting the algæ filaments growing near the vent of the spring. When cold the water is not peculiar in taste or in odor, but it is considered unfit for drinking, owing to the large amount of carbonate of lime which it holds in solution.

At many of the springs a large amount of gas escapes as the water issues from the vent, which is proven by analysis to consist of carbonic acid gas, oxygen, and nitrogen. Although the odor of sulphur is very noticeable and sulphur is deposited at many of the springs, the amount of sulphuretted hydrogen present in the water is very small, and is too minute to appear in the analysis of the waters. The general character of the water is the same in all the springs, but the amount of mineral matter held in solution varies at different springs from 15 to 17 parts in 10,000, and of this one-third consists of carbonate of lime and the remainder of readily soluble salts.

In the following table analyses are given of typical waters from the Mammoth Hot Springs, and also of the surface waters of the surrounding slopes. These analyses were made by Prof. F. A. Gooch and J. E. Whitfield,[3] for the Geological Survey of the Yellowstone National Park. In the same table analyses for comparison are given of the thermal waters of Hierapolis and Kukurtlu,

[1] Hunt. loc. cit. and Skey, in Trans. New Zealand Inst., vol. 9, p. 454

[2] Hunt, loc. cit., p. 50.

[3] Analyses of Waters of the Yell. Nat. Park, Bull. No. 47, U. S. Geol. Survey.

Asia Minor, made by J. Lawrence Smith,[1] and also of the Carlsbad sprudel, made by Ragksy.[2]

*Analyses of waters from the Mammoth Hot Springs.*

| | Cleopatra. | Orange. | 136° F. Hot River. | Gardiner. | Hotel water. | 130° F. Hierapolis. | 182° F. | Carlsbad. |
|---|---|---|---|---|---|---|---|---|
| $Ca\,Cl_2$ | 0.0009 | ........ | ........ | ........ | ........ | 0.020 | ........ | ........ |
| $NH_4Cl$ | 0.0019 | ........ | 0.0003 | ........ | ........ | ........ | ........ | ........ |
| $Li\,Cl$ | 0.0140 | 0.0097 | 0.0068 | Trace. | ........ | ........ | ........ | ........ |
| $Na\,Cl$ | 0.1903 | 0.1636 | 0.1855 | ........ | ........ | ........ | ........ | 1.0306 |
| $K\,Cl$ | 0.0976 | 0.1165 | 0.0882 | 0.0103 | 0.0046 | ........ | ........ | ........ |
| $K\,Br$ | Trace. | Trace... | ........ | ........ | ........ | ........ | ........ | ........ |
| $Na_2\,SO_4$ | 0.1448 | 0.1834 | 0.2265 | 0.0161 | 0.0448 | 0.341 | 0.1950 | 2.3721 |
| $K_2\,SO_4$ | ........ | ........ | ........ | 0.0056 | 0.0015 | ........ | 0.0202 | 0.1636 |
| $Mg\,SO_4$ | 0.3645 | 0.3295 | 0.3155 | ........ | 0.0076 | 0.431 | ........ | ........ |
| $Ca\,SO_4$ | 0.1953 | 0.2002 | 0.1450 | ........ | ........ | 0.119 | 0.1710 | ........ |
| $Al_2\,(SO_4)_3$ | ........ | ........ | ........ | ........ | ........ | ........ | 0.0043 | ........ |
| $Na_2\,B_4\,O_7$ | 0.0326 | ........ | 0.0185 | ........ | ........ | ........ | ........ | ........ |
| $Na\,As\,O_2$ | 0.0041 | ........ | 0.0004 | ........ | ........ | ........ | ........ | ........ |
| $Ca\,CO_3$ | 0.6254 | 0.5580 | 0.4833 | 0.0625 | 0.0790 | *1.368 | *0.1830 | 0.2978 |
| $Mg\,CO_3$ | ........ | ........ | ........ | 0.0018 | 0.0258 | *0.041 | *0.0460 | 0.1240 |
| $NaH\,CO_3$ | ........ | ........ | ........ | †0.0340 | ........ | 0.078 | ........ | †1.3619 |
| $Fe\,CO_3$ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 0.0028 |
| $Mn\,CO_3$ | ........ | ........ | ........ | ........ | ........ | ........ | ........ | 0.0006 |
| $Al_2\,O_3$ | 0.0093 | .0022 | 0.0097 | 0.0079 | 0.0021 | ........ | ........ | ‡0.0004 |
| $Si\,O_2$ | 0.0517 | 0.502 | 0.0500 | 0.0469 | 0.0355 | 0.008 | 0.1100 | 0.0728 |
| Total solids | 1.7315 | 1.6133 | 1.5297 | ........ | ........ | 1.934 | 0.970 | 5.4312 |
| Total $CO_2$ § | 0.3537 | .0924 | 0.2143 | 0.0286 | 0.0748 | (0.3520) | ........ | 0.7604 |
| Summation | 2.0852 | 1.7057 | 1.7440 | 0.2137 | 0.2757 | ........ | ........ | ........ |

* Bicarbonate. † Neutral. ‡ $Al_2\,(PO_4)_2$. § Free.

The analyses show that the amount of carbonate of lime held in solution in waters of the Mammoth Hot Springs is greatly in excess of that which the carbonic acid of the water is capable of dissolving. In the Cleopatra water, which contains the greatest amount of carbonate of lime, viz, 0.6254 parts in 1,000, the excess of carbonic acid over that necessary to form the neutral carbonate is 0.3537 gramme per litre. If this were united to form bicarbonates, the excess of free carbon dioxide would be but 0.0786 gramme. But as water saturated with carbonic acid, that is, containing 2 grammes per kilogramme, will dissolve but 0.88 gramme carbonate of lime, the proportionate amount dissolved by 0.3537 gramme of carbonic acid will be 0.1552 gramme of carbonate of lime. Since the water actually contains 0.6254 gramme of carbonate of lime in solution in each kilogram of water, there is an excess of 0.4698 gramme of carbonate of lime which has been dissolved either by increased pressure or by the alkaline salts present. As the water has been under pressure,

[1] Original Researches, p. 63.

[2] Carlsbad, Marienbad, etc., u. ihre Umgebung: Prag 1862, p. 76.

which was relieved as it rose to the surface, this has probably influenced the solution of the carbonate of lime, but the effect of the salts present is undoubtedly very important.

The Hierapolis waters contain 0.937 gramme of carbonate of lime per kilogram, considerably more than the Cleopatra water, with 0.3520 gramme of carbonic acid which can dissolve but 0.1549 gramme of carbonate of lime, leaving 0.7820 gramme of the latter to be dissolved by the 0.772 gramme of magnesium and sodium sulphates present, combined with the increased pressure under which the water existed before reaching the surface.

The Cleopatra water is supersaturated as it issues from the spring, since it deposits a small amount of calcic carbonate upon standing in tightly stoppered bottles. This supersaturation is probably due to the relief of pressure as the water rises in the tube of the spring and issues from the vent. As the water flows over the travertine slopes and basins there is a loss of carbonic acid and a deposition of carbonate of lime. At the same time the water is concentrated by evaporation owing to the large surface exposed. A small sample of water was collected from the slopes of the mound of the Cleopatra spring, at a point 25 feet below and distant 50 feet horizontally from the point of issue. The water, in flowing this distance, had cooled from 156° F. down to 113° F., and had lost 4 per cent by evaporation. This result is reached by a comparison of the sulphuric acid found in the water of the spring with that in the water of the slope. Correcting for evaporation, a comparison of the analysis with that of the spring water shows a loss of 0.2251 gramme per kilogram of carbonic acid by diffusion, and the deposition of 0.1675 gramme of carbonate of lime in flowing this short distance. Notwithstanding the deposition of this amount of calcium carbonate, the water was supersaturated with that salt, for it deposited carbonate of lime upon standing in a tightly stoppered bottle, probably because of the loss of the carbonic acid and the concentration of the water in flowing down the slope.

## DEPOSITION OF CARBONATE OF LIME.

As the presence of carbonic acid gas is essential to the permanence of a solution of carbonate of lime, whether the solution contains alkaline and earthy salts or not, the withdrawal of the carbonic acid will cause a supersaturation of the liquid with a gradual separation and precipitation of the lime carbonate. Thus deposits of carbonate of lime may be due to the following causes :

(1) Relief of pressure.
(2) Diffusion of the carbonic acid by exposure to the atmosphere.
(3) Evaporation.
(4) Heating.
(5) Influence of plant life.

Where the solution has been formed under pressure, the increased amount of carbonic acid which the water is then capable of retaining permits the solution of a larger amount of carbonate of lime. Upon the relief of this pressure the excess of gas escapes, and an unstable, supersaturated solution results, from which the lime carbonate gradually separates out. In this way originates the troublesome incrustations inside the pipes of pumps, and the saturation of many spring waters is undoubtedly due to the relief of pressure as the water issues from the ground.

Richly carbonated waters lose a portion of their carbonic acid upon exposure to the air; simple standing is sufficient to cause the separation of lime carbonate upon the surface of pools of such solutions, and the diffusion of the carbonic acid is proportionate to the temperature. Deposits formed in this way are common on the bottom of stagnant basins at the Mammoth Hot Springs, where the pellicle of carbonate of lime forming upon the surface breaks up on thickening, and falling to the bottom accumulates as a flaky, loose deposit. This diffusion of carbonic acid gas by exposure to the air is greatly facilitated by increasing the surface exposed, as well as by the agitation of the water; this is the case where the water spreads out over a surface in a thin sheet, or in cascades and spray. This diffusion is generally accompanied in such cases by evaporation, which also produces a separation of the lime carbonate. Stalactites, and similar formations common in limestone caves, are produced by these causes acting simultaneously, and the "petrified" or really incrusted bouquets, baskets, etc., of Carlsbad and many European springs, and also the Mammoth Hot Springs, are covered with crystals of calcite deposited in this way. (Fig. 53.)

Evaporation alone causes the formation of deposits of lime carbonate, in the form of *tufa*, by a concentration and supersaturation of the water. Such deposits are of great extent about several of the lakes of the Great Basin, as described by King, and Hague,[1] and lately by I. C. Russell.[2]

Heat causes a precipitation of the lime carbonate by a double action, driving off the carbonic acid and diminishing the solvent effect of the alkaline and earthy salts present,[3] resulting in the formation of boiler scale and incrustations where lime-bearing water is used for generating steam.

Deposits of carbonate of lime are also formed from natural waters by chemical reaction, as in the case of the tufa cones and tubes formed about the sublacustrine springs of Mono Lake.[4]

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[1] Geol. Explor. of the 40th Par.: vol. 1, p. 514; vol. 2, p. 822.

[2] Lake Lahontan: Monograph No. 11, U. S. Geol. Survey.

[3] Skey: Trans. New Zealand Inst., vol. 10, p. 449.

[4] Russell, loc. cit.

### DEPOSITS OF CARBONATE OF LIME DUE TO PLANT LIFE.

In the formation of the deposits just discussed, it is evident that plant life takes no part. It has, however, been long known that many water plants possess the power of abstracting carbonate of lime even from waters exceedingly poor in this salt, as in the case of sea water, where the Corrallines and other marine algæ build their framework of lime carbonate. Many fresh water plants, especially the *Charæ* and some mosses, also produce a separation of carbonate of lime. Our knowledge of this subject is chiefly due to the researches of Dr. Ferd. Cohn, who has shown the life of mosses and of algæ to be a most energetic factor in the formation of deposits of travertine.

The warm mineral waters of Carlsbad contain an abundant algous vegetation which forms thick cushions of jelly on the sides of the stream channels and generally wherever the warm waters flow. The association of this growth with the deposition of travertine is very striking, and early writers upon the vegetation of the springs called certain species lime-incrusted. Dr. Cohn was the first to discover the true relation of this plant life to travertine deposition, and in a paper published in 1862 he showed that these algæ actually eliminate carbonate of lime from the water and form travertine.[1] In proof of this he states that if a part of the algous jelly be pressed between the fingers an extremely fine sand is felt between the tips of the fingers, the grains being much larger if the jelly is taken from the older and lower parts of the growth. The nature of this sand and its true relation to the vegetable tissue are easily recognizable, the microscope showing minute crystals of carbonate of lime in the slime between the vegetable threads and upon their surface. These crystals, which at first are separate, increase in number and form star-like clusters, which by enlargement grow into grains of calcareous sand. By the further deposition of carbonate of lime these grains grow together and are cemented into solid travertine. All these steps are said to be recognizable under the microscope with the aid of hydrochloric acid.

The explanation of this deposition of lime carbonate within and upon the vegetable tissue is said to be the physiological action of the plant, which by withdrawing carbonic acid from the water diminishes the amount of carbonate of lime which it is capable of retaining in solution, the excess crystallizing out in the manner described. The supply of the soluble bicarbonate of lime withdrawn from the water by this double action of the plant is renewed by endomatic circulation. The cementing together of the grains of sand, which takes place in the older and deeper layers of the algous mass, is

[1] Die Algen des Karlsbader Sprudels, mit Rücksicht auf die Bildung des Sprudel sinters: Abhandl. der Schles. Gesell. pt. 2 Nat., 1862, p. 35.

thought to be largely due to a process independent of plant life, in which the porosity of the tufa plays a part.

The exact relation of the crystals and grains of carbonate of lime varies in the different species of algæ. In the *Oscillariæ* of Carlsbad, and allied species, the crystals form in the slimy inter-cellular tissue; in *Halimeda*, the carbonate of lime forms a sieve-like cover about the tips of the algæ filaments, and in *Acetularia* it occurs as a tube about the stalk of the plant. In the *Charæ* the lime is separated and deposited in the cells and cell walls of the back alone, while in the *Corallines* it is found only within the cells.

It has already been stated that the algous vegetation of the Mammoth Hot Springs also produces a separation of carbonate of lime. A careful study of this vegetation in the field and under the microscope shows that this process is similar to that discovered by Dr. Cohn. At Carlsbad it was found that no vegetation was present and no tufa was deposited where the temperature exceeded 131° F. (44° R.), but with the appearance of algæ in the water the deposition of travertine began. A similar statement can not be offered in proof of the influence of such growths in the deposition of carbonate of lime at the Mammoth Hot Springs, for one species of algæ is found at 165° F., the hottest water of this locality. But that the algæ of these springs secrete carbonate of lime and form travertine can be satisfactorily demonstrated, and the process may be observed wherever the hot waters flow.

Masses of gelatinous vegetable growth, closely resembling those of the Carlsbad sprudels, are found about many of the springs, notably those at the north base of Capitol Hill and at the Jupiter Springs. In this vegetable jelly thin and flaky layers of carbonate of lime are found in the plant tissue. An examination of this gelatinous substance shows that it is composed of successive membrane-like sheets, in which minute gritty particles can be felt with the fingers. Under the microscope isolated little crystals and stellate accretions of these crystals are found scattered about in the plant tissue. These by further growth form minute grains of carbonate of lime. In the older layers and on the surface of this flaky travertine all sizes of grains are found, the largest being one millimeter in diameter.

This deposit is made up of these pellets, plainly seen in the freshly formed tufa layers, but indistinguishable in the older layers, where the grains are cemented together and the oolitic structure is lost. This cementation of these pellets and of the thin laminæ forms a firm, more or less compact, travertine. The membranous structure of the Carlsbad growth is supposed to be due to the intermediate or intercalated layers of carbonate of lime, ascribed to a certain periodicity of outflow from the spring, the temperature being constant. The same structure found at the Mammoth Hot Springs is not neces-

sarily due to this cause, since alterations in the amount and temperature of the current nourishing the algæ may be caused by the obstructive growth of the plants themselves, which thus produces a change in both the vegetation and the deposit. In addition to this, evaporation and loss of carbonic acid from the water flowing over the surface of the growth cause the formation of a crust of carbonate of lime, which is afterwards covered by algæ, as the water dammed by the growth below is forced to flow over this surface.

If the water supply be cut off from a mass of such algous growth the plants die, the green changes to brown, and this to rose pink, and finally to a light salmon, while the odor of decaying vegetable matter is very perceptible. In a short time all color fades from the surface and a soft and porous chalky deposit is all that remains of the mass of jelly-like algous growth. If a little moisture is present the pink tint remains a long time, and is generally noticeable in the inner parts of the deposit. Such areas are common at the Mammoth Hot Springs, especially about the changing vents of sulphur springs, and at numerous places where warm waters have issued from little vents early in the season, but have dried up on the advance of summer, leaving this pink tinted and soft deposit as the only evidence of the recent outflow.

As already mentioned, the escape of carbonic acid and the evaporation of the water are very rapid on the overflow slopes, below the Main Springs. In consequence of this, a coating of pure white crystalline carbonate of lime is rapidly deposited upon objects of any kind placed in the spray of the hot water, a thickness of $\frac{1}{20}$ to $\frac{1}{16}$ of an inch being formed in three days under favorable circumstances. This incrusting property of the water is utilized for the production of coated "specimens," made to sell to tourists. Horseshoes, pine-cones, bottles, and different forms of wire work are placed on rude racks, or suspended from the cross-bars of the rack by strings and the hot water led over them so that the objects to be coated are constantly wetted by the hot spray, as shown in Fig. 53. The deposit so formed is pure white and marble-like, and the little crystals sparkle in the light. If, however, the objects be permitted to remain in the spray several days longer, the deposit loses its intense whiteness and assumes a dull yellowish tint. At the same time the former smooth surface of the coating is dotted with wart-like excrescences which become larger and more numerous the longer the specimen is exposed, and in time will distort and disguise the original shape of the object, while the color becomes a rich umber brown. By treating specimens of this character with dilute hydrochloric acid these changes are seen to be due to the growth of algæ. The first points of growth are places of most rapid deposition, and warty excrescences are formed; later the algæ are present all over the surface and the thick coating becomes dendritic in structure, and both color and form sug-

gest organic life. In such deposits vegetable life is not, however, the only factor, since we have seen that the water will deposit a coating of carbonate of lime without the influence of plant life. But these influences are eliminated if we place such objects under water, in the bowl of either of the main springs; for bottles, horseshoes, or other articles of glass or iron immersed in these springs for a long time were not coated.

If, however, a pine branch, a part of some bush or plant, be placed under the water it is shortly covered with an incrusting cylinder of carbonate of lime. The surface of this cylinder is reddish brown and warty, resembling the deposit last mentioned; the interior is dendritic in structure and of a light buff color. This deposit closely resembles the travertine cylinders formed about twigs and branches at Tivoli. In the formation of these cylinders at Tivoli, Cohn has shown[1] that crystalline sinter is only separated about living plants whose bark is covered with growing algæ and mosses. In our deposits the nature of the substance immersed is important only because it affects the ability of the algæ to obtain a foothold and to grow, and the deposition of sinter is coincident with the growth of such algæ.

A portion of this deposit dissolved in dilute hydrochloric acid leaves a residue of tangled algous filaments, forming a felt-like mass. The nodular masses common on the bottom of hot water pools and basins are similar in nature; the surface of these formations is moss-like, brown and greenish in color, particularly in the depressed portions. The interior is formed of buff-colored tufa of radiating dendritic fibers.

## DESCRIPTION OF THE DEPOSITS.

The different varieties of travertine found at the Mammoth Hot Springs vary in physical structure and in appearance, according to the conditions under which the deposit was formed. In general, the compactness of the travertine depends upon the rapidity of formation, some of the most quickly formed deposit being so light and porous that it is easily crumbled to powder between the fingers, while the slowest formed deposit is almost flint-like in texture.

The travertine of the older terraces is often compact, dense, and hard, resembling an ordinary limestone; another variety, often of recent formation, is also compact and crystalline, resembling the purest of marble; while the freshly formed walls of the basins of the Main Terrace are often soft and easily crushed. Notwithstanding the marked differences of structure and appearance the travertine all has the same chemical composition as shown by analysis.

The following analyses, made for the Geological Survey of the

[1] Neues Jahrbuch (Leonhard), 1864, p. 580.

Yellowstone National Park, by Mr. J. E. Whitfield, show the composition of typical specimens of varying forms of the Mammoth Hot Springs deposit; analyses are also given of travertines from other localities.

*Analyses of Travertines.*

| | I. | II. | III. | IV. | V. | VI. | VII. | VIII. | IX. |
|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$, silica ........ | 0.08 | 0.26 | 0.06 | 0.01 | 0.15 | ........ | 0.6 | 0.30 | 0.12 |
| $Al_2O_3 + Fe_2O_3$ ..... | 0.15 | 0.11 | 0.14 | 0.05 | 0.49 | ....... | ........ | 1.10 | ....... |
| $SO_3$, sulph. acid ..... | 1.72 | 1.34 | 0.70 | 0.49 | 0.55 | ..... . | ....... | 0.80[a] | 0.08[a] |
| CaO, lime ........... | 53.83 | 54.06 | 55.02 | 55.02 | 53.46 | ....... | ....... | ....... | ... .... |
| $CaCO_3$, lime carbonate ............... | *(94.97) | *(95.77) | *(96.02) | *(96.02) | *(95.36) | 96.82 | 98.02 | 97.00 | 95.62 |
| MgO, magnesia .. .. | 0.90 | 0.60 | 0.06 | 0.07 | 0.42 | ... ... | ....... | 0.16[b] | 3.06[b] |
| NaCl, sodium chloride............... | 0.02 | 0.26 | 0.20 | 0.12 | 0.13 | ..... .. | ... .... | ....... | ........ |
| $K_2O$, potash ......... | ........ | ........ | 0.08[c] | 0.04 | 0.01 | ....... | ... .... | ........ | 0.107 |
| $CO_2$, carbonic acid .. | 41.79 | 42.14 | 42.25 | 42.25 | 41.96 | ........ | ........ | ........ | ........ |
| $H_2O$, water..... .... | 1.43 | 1.19 | 1.06 | 1.61 | 2.44 | 1.30 | ... ... | ........ | ........ |
| C, carbon............ | 0.21 | None.. | 0.24 | 0.11 | 0.37 | ... ... | ... .... | ........ | ........ |
| Other constituents .. | ........ | ........ | ........ | ........ | ........ | 1.41 | 1.20 | ....... | ....... |
| Total . ....... .... | 100.13 | 99.96 | 99.81 | 99.77 | 99.98 | 99.94 | 100.00 | 99.36 | 99.39 |

[a] Sulphate of lime. [b] Carbonate of magnesia. [c] Potassic chloride

*If all the $CO_2$ be supposed to be combined with lime.

No. I is a compact yellowish travertine from the slopes below the Hotel Terrace, and it represents the older travertine.

No. II is the riffled travertine forming the ridge west of the Blue Springs and above Cupid's Cave.

No. III is the fibrous white travertine forming the fan-shaped masses seen in the Blue Springs and elsewhere, the specimen being from a deserted vent near the Blue Springs.

No. IV is from a mushroom-shaped mass, showing the color and structure of the organic growth found in the overflow of spring No. 24.

No. V is the crystalline travertine found on the walls of Cupid's Cave. The surface is satiny and mottled, with spicules and beaded formations resembling siliceous sinter.

No. VI is the analysis of the Carlsbad sprudelstein made by Berzelius.[1]

No. VII and No. VIII are travertines from Hierapolis and from Kukurtlu, Asia Minor, analyzed by J. Laurence Smith.[2]

No. IX is the tufa found about the Arkansas hot springs, analyzed by David Dale Owen.[3]

Though travertine formed without the presence and aid of plant-life forms but a very small part of the bulk of the Mammoth Hot

[1] Annalen der Physik, Gilbert: vol. 74, p. 168.

[2] Original Researches, p. 65.

[3] Geology of Arkansas.

Springs deposit, there are two interesting varieties in the formation of which vegetable life was absent. The first is the thin flaky deposit found at the bottom of stagnant pools and basins of the spring water. This is formed by a separation of calcic carbonate at the surface of the pool, owing to the diffusion of carbon dioxide upon prolonged exposure of the water, forming a thin wax-like film upon the surface; this thickens until the crust breaks up from its own weight and the flakes settle to the bottom of the basin. This material is nearly pure carbonate of lime, whose specific gravity, 2.70356, shows it to be a true calcite.

Another variety also made independently of plant life is that which forms the lining of hot-spring chambers, such as the Devil's Kitchen, and the spring vent-holes. This is deposited comparatively slowly, and occurs in shelly layers half an inch to three inches thick, with a smooth, rounded, and globular surface. It is crystalline and marble-like and pure white. This travertine is a crystallization out of a supersaturated solution of carbonate of lime, due to the relief of pressure as the waters approach the surface. A similar deposit lines the vent-holes of the Orange and other springs, and is analogous to the deposits so quickly formed in the conduit pipes leading the hot water to the hotel baths, also due to supersaturation, experiments showing that such solutions do not deposit their excess of lime at once, but in the course of a short time.

All other varieties of the travertine so far found have been formed partially or entirely by the aid of plant life. Of the numerous forms produced in this way there is none which shows its vegetable origin more clearly than the fibrous tufa forming the fan-like masses found in many of the springs. (Fig. 52.) A simple examination of this deposit with a lens shows that the fibers are neither long crystals nor crystal aggregates, and the stringy or blade-like fibers suggest the incrustation of vegetable filaments. The upper surface of this deposit is fairly even and the fibers round and parallel in arrangement. The inner part of the specimen is similar, but the fibers are sharper and resemble blades of grass arranged loosely, giving an open and porous structure. The under surface of these fans is more uneven, the fibers are round and covered with little pellets of lime sometimes clustered in botryoidal forms, while the threads themselves are irregularly arranged, as if a skein of silk floating in the shifting currents of a stream were suddenly turned to snowy travertine. Plate LXXXI shows the upper surface of a part of one of these travertine fans, on which the travertine frost-work is particularly beautiful. The specimen is formed of a stringy or fibrous deposit covered by gnarled and knotted ropy forms, whose surface is covered by aggregated travertine pellets of varying sizes up to one-eighth of an inch in diameter, these in turn coated with a drusy frost-work of little crystals. Bubble-like shells of translucent wax-

like travertine, sometimes entire, oftener broken, lie between the fibers or entangled in the network, their broken edges beaded and their surface dotted with minute pellets of the same material. An examination of a fragment of this porous fibrous travertine with a pocket lens shows that the fibers, tubes, and blades are built up of minute rods lying alongside of one another and cemented into bundles or plates. Each rod has a hard vitreous center, with an outer more opaque coating. Dissolving a little fragment of the travertine in dilute hydrochloric acid shows that each little rod is formed by a single algæ thread. Remembering the occurrence of the fans of this fibrous travertine, we can only conclude that the formation is produced by the white species of algæ so common in the hotter waters of the springs.

The curious mushroom-shaped forms found in the channels of many of the springs are detached with difficulty, as the deposit is quite hard when fresh. The top is usually wet by the ripples and spray of the stream, but is above the general body of water. This upper surface is riffled by a network of little ridges one-eighth of an inch high, with basin-like depressions between. The color is a bright orange red, which is most brilliant in the depressions, where one familiar with algæ at once recognizes the vegetable nature of the color. A transverse section of the specimen proves that it is also of algous origin. The stem consists of fibrous travertine resembling that forming the "fans." This forms the center or middle layer of the cap of the toadstool also, but is overlaid by a layer one-quarter to three-quarters of an inch thick of quite different structure. This top layer is also fibrous, but the fibers are short, stout, and perpendicular to the underlying deposit. The under side of the cap is coated with hard, porcelanous travertine, with smooth surface, often dotted with botryoidal clusters of white pellets, to which sulphur-coated filaments are often attached. Both varieties of fibrous travertine show a netted mass of algæ filaments when dissolved in dilute acid. The most common variety of travertine, forming the riffled surfaces of the rounded slopes, benches, and terraced basins, is like that forming the top layer of the mushroom forms just mentioned.

The riffled surface is due to innumerable little ridges which run across the surface in wavy lines, and, meeting, form miniatures of the larger basins. If the slope is very gentle these little basins are proportionately larger and the dividing walls very thin, while on steeper slopes the ridges are thick and close together, producing a reticulated surface. While wet by the hot water the color is generally quite brilliant. If the volume of water be large and the current rapid, the color is a creamy white, shading at the shallower and less rapid parts of the overflow into pale salmon and pink, and these to orange, red, and burnt sienna. If this deposit be examined with a lens the

TRAVERTINE, MAMMOTH HOT SPRINGS.

color is seen to be due to a fuzzy growth of algæ, and if a fragment be carefully dissolved in dilute hydrochloride the fuzzy coating is found to be only the tips of the living ends of algæ threads buried in the deposit beneath. The structure is fibrous and quite like the upper layer of the form last described. Where the travertine forming the riffled slopes is broken down, showing its general structure, it is seen to consist of concentric shells or curved plates of varying density and thickness. This evidences varying conditions of deposition, such as changes in the supply, and consequently of temperature, affecting the nature of the plant growth.

Changes of structure are easily produced in this way, as the compactness of the deposit depends largely upon the rapidity of deposition, being least where most quickly formed. Changes may also be due to the effect of sudden cold or the different seasons, as intense cold might kill the plant growth, and the less evaporation of the winter months, with a probable less vigorous growth of the algæ, would produce a thinner, more compact layer of sinter. In general it may be stated that variations in evaporation and in the growth of the algous vegetation will produce variations in the structure of the deposit.

Another common variety is formed of overlapping layers of fibrous travertine, resembling a thatched roof; it is but another form of that making the fan-shaped masses and is produced by either the white or green filamentary algæ. This deposit originates the pillars of the Pulpit Basins and of others like them.

At the edges of the Main Springs is a very hard laminated sinter formed by the evaporation of the water but tinted by the plant life present. The lining of these bowls and of the adjoining pools is formed of a mossy deposit already described.

Coralloidal travertine is found in many quiet basins and pools where the water is concentrated by evaporation and the lime crystallizes out upon the web of algæ threads present in the water, producing very delicate forms resembling certain species of corals. Sometimes such deposits support the pellicle of lime gathering on the surface, and thus the pool is completely roofed over. The stems of this variety of tufa are thickly set with a drusy coating of crystals arranged perpendicularly to the surface of the stem. The honeycombed deposit found in many of the dry and empty basins is formed by the rising of gas bubbles through the soft, gelatinous mass of the algæ, the tubes remaining open during the conversion of the growth into solid travertine.

## WEATHERING OF THE TRAVERTINE.

Deprived of their supply of water, the travertine slopes lose their brilliant colors, which soon fade out, leaving a chalky white surface; this darkens by prolonged exposure to a light gray and in a few

years to the dull gray tone of the older deposits. This gray tint is only a surface coloration, for the deposit beneath is still pure white.

Frost is the greatest foe to the preservation of the basins and terraces. In winter the cool overflow from the springs, with rain and melted snow, freezes upon the surface of the deposit, and thickening, tears off the walls of the terraced basins by its weight, or freezing in the porous travertine and in its cracks and fissures, opened by the settling of the deposit, pries off and loosens many of the most beautiful forms of the tufa. A judicious distribution of the overflow from existing springs would, however, rebuild and repair many of the ruined and crumbling slopes and basins without detracting from the beauty of other parts of the deposit.

Infiltrating waters from the overflow of the springs carrying carbonate of lime, effect a change in the open and porous tufa, hardening it into a denser and more compact rock. The travertine is also altered by steam and sulphurous vapors rising through it; steam alone often produces a coarsely granular structure of loosely compacted crystals. Where the vapors are sulphurous the tufa is converted into acicular crystals of gypsum, generally preserving the open structure of the travertine, with sulphur deposited in the open spaces.

## ORIGIN OF SILICEOUS SINTER.

With the exception of the calcareous waters of the Mammoth Hot Springs already described, and a few less important localities, the hot waters of the Yellowstone National Park, like those of other volcanic areas, are characterized by the proportionately large amount of silica contained in solution. These springs, like those of Iceland, may be divided into two groups, of acid siliceous and of alkaline siliceous waters—a distinction quite sufficient for the purpose of this article. The acid waters include the Highland springs, those of Crater Hills and several other localities in the Park, and are generally characterized by deposits of sulphur and efflorescent alum salts, while the waters contain free hydrochloric or sulphuric acids. The alkaline springs form the largest of the two groups, comprising the geysers and the other hot springs of the Geyser Basins, and similar hot-spring areas.

About these alkaline hot springs the mineral deposits consist almost entirely of silica, partly as opal in the clay and less decomposed rhyolite, but chiefly as siliceous sinter, a surface incrustation of white amorphous silica. This sinter forms the mounds and cones of the geysers and springs, the fretted and scalloped rims of the quieter pools, and the great white flats surrounding the springs.

Although such deposits of siliceous sinter are found wherever geyser action is manifested, and quite commonly in connection with alkaline hot springs in all parts of the world, the deposits of Iceland, New Zealand, and the Yellowstone Park are much the best known

and far exceed those of other localities. The Iceland deposits have been known the longest, and have been studied by many observers. The Haukadal area is the most familiar, as it is here that the Great Geyser is situated. At this place the white sinter deposits cover many acres of ground and form the snow-white basins of the quietly boiling springs, and the mounds of Strokr and the Geyser.

The New Zealand sinter areas are similar in character, but the deposits are much more extensive than those of Iceland. In many parts of the North Island there are sinter flats and mounds resembling the Iceland and Yellowstone deposits, but in neither of these countries is there anything to equal in beauty the wonderful stalactic basins of the pink and white terraces of Lake Rotomahana, which were destroyed in the volcanic outbreak of 1886. The sinter deposits of the Yellowstone National Park are, however, the largest known, covering many square miles at the different geyser basins and other hot spring localities. There is probably no better field in which to study the different varieties of silica deposited by hot spring waters and to observe the conditions under which they are formed. In the series of observations carried on by the writer, it has been found that a large proportion of the siliceous sinter of the different geyser basins is formed by the agency of vegetable life, algæ and mosses living in the siliceous water, and it is these deposits and their origin that are of special interest in this part of the present paper.

The formation of siliceous sinter by plant life has been found to be going on at many hot-spring areas in the Park, in fact wherever alkaline siliceous waters are found; but since it is necessary to select some particular place where the details of such growths may be described, the Upper Geyser Basin of the Firehole River is chosen, as it is easily accessible and is seen by all visitors to the Park.

## UPPER GEYSER BASIN OF THE FIREHOLE RIVER.

### GENERAL DESCRIPTION.

The Upper Geyser Basin of the Firehole River lies 10 miles west of Yellowstone Lake, 39 miles south of the north boundary, and 11 miles east of the western boundary of the Park, and is reached by a stage ride of 8 miles from the Lower Firehole, or of 50 miles from the Mammoth Hot Springs. The altitude is about 7,300 feet above sea level, but though the basin is quite near the continental divide which separates the drainage of the Pacific from that of the Atlantic Ocean, it occupies a well-marked depression in the great rhyolite plateau of the Park. Situated almost on the crest of the continent, it is yet somewhat distant from the mountain ranges of the Park, and is about equally removed from the Gallatin range on the north, the volcanic peaks of the Absarokas on the east, and the Teton uplift on the south.

The area of about two square miles comprising the Upper Basin, as it is commonly called, has a fairly level surface, $1\frac{1}{4}$ miles in extreme width, and $2\frac{1}{4}$ miles long. This is inclosed between the abrupt cliffs of the Madison Plateau on the west and north and the heavily wooded slopes of the continental divide on the south and east. The rhyolite which forms these barrier walls, and is well exposed in the cliffs about the basin, also forms the floor of the valley itself, but is generally concealed either by a sheet of siliceous sinter in the vicinity of the hot springs, or by its own débris, a black pearlitic sand. The Firehole River and its branches, the Little Firehole and Iron Creek, drain the basin; the Firehole flows through the eastern part of the area, and most of the geysers and hot springs are situated upon or close to its banks. Except where covered by sinter or hot water marsh, the surface is timbered with a thick growth of pine (*Pinus Murrayana*), and scattering trees are also found over the older, disintegrating deposits of sinter. These sinter areas form the most

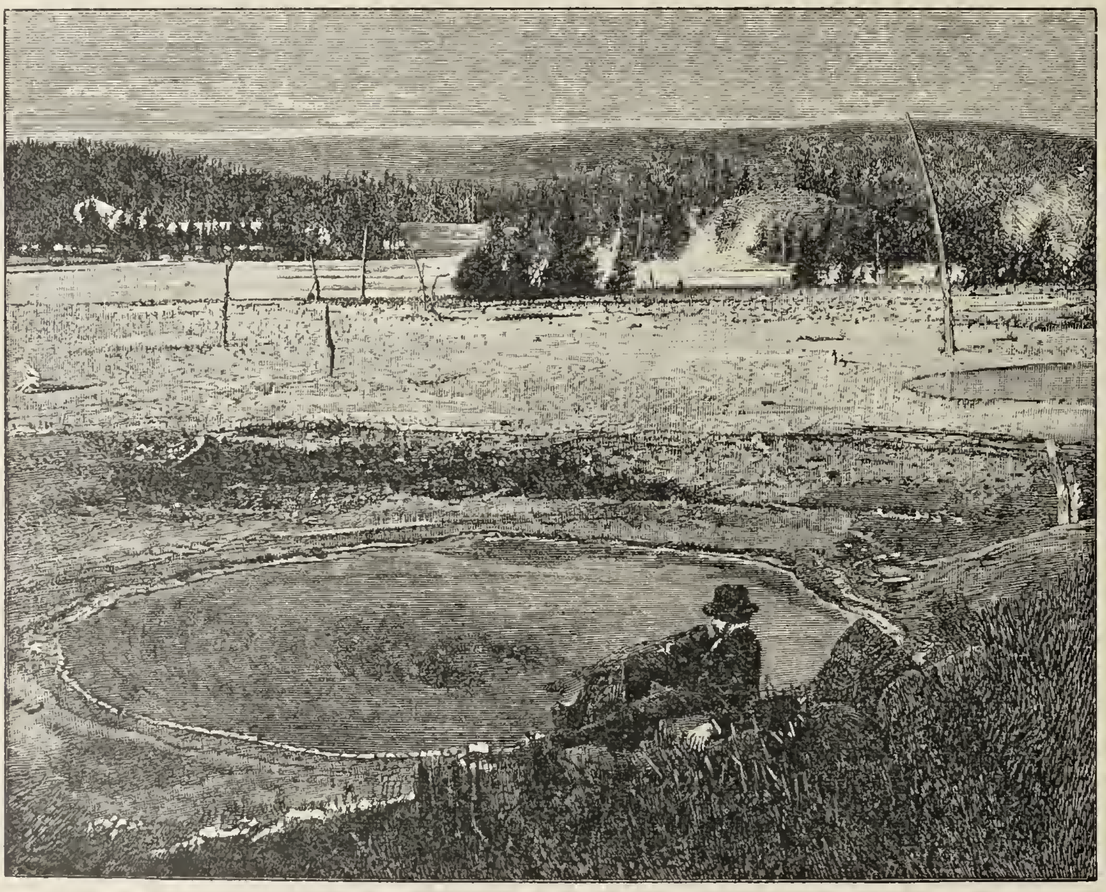

FIG. 54. General view of part of the Upper Geyser Basin.

striking feature of the topography of the basin, and the bare white flats and sinter mounds are in strong contrast with the dark green of the neighboring forest. The mass of sinter deposited by the hot water is so large that it has materially changed the original surface of the ground. Fig. 54 shows the appearance of the central part of the main geyser area, seen from the slopes near the Grand Geyser.

This sinter covering is variable in thickness, the maximum depth being about thirty feet around several of the older vents, a thickness which attests the great age of the thermal action. The sinter sheet is constantly extending its boundaries, as shown by dying and dead trees and other vegetation standing in the silica, but a gradual dying out of the older vents permits a slight surface disintegration of the deposit, with a gradual encroachment of vegetation upon it.

But few of the many hundred springs of the Upper Basin are turbid or muddy, and the pools are generally characterized by the exquisite clearness of the water, which appears of varying shades of blue or green, according to the depth and amount of light admitted. If the water be quiet, the transparency is such that the minute details of the basin can be seen, even at depths of 20 feet or more. In the quieter springs, where the temperature does not exceed 150° F., the basins are often lined with a more or less abundant algous growth, whose orange, red, yellow, brown, and green tints impart new shades to the water. Though there are many of these *laugs* the greater number of springs possess a temperature approaching or equaling 198° F., the boiling point at this altitude, and in such springs the water is usually in constant or intermittent ebullition. Around the margins of such springs a rim of silica is generally built up by the hot waters. The inner surface, where constantly wet by steam and spray, is a bright, tawny yellow, the deposit being sponge-like in form and in color, though composed of hard silica. The outer surface of these rims is generally gray, often ornamented with pearls or beadwork of most delicate structure.

At the margins of more tranquil springs a flat projecting crust or edging of white sinter is found, sometimes extending out over the water and even roofing over parts of the spring, as shown in Fig. 55. This edging of white sinter is oftentimes scalloped in outline, each scallop closely resembling fungus growths common on the bark of trees in damp woods. Many of the springs have received appropriate names, such as Sapphire Pool, the Morning Glory, and Chromatic Spring, but many more, perhaps equally beautiful, remain unnamed. It is not easy to draw a sharp line between hot springs and geysers, nor is it at all necessary; for there is every gradation, from a quiet pool with simple intermittent increase in temperature to the great fountains of boiling water which provoke our wonder and our admiration. Forty-eight geysers are known in this basin each possessing such peculiarities of eruption or surroundings as to make it of interest and distinguish it from its fellows. Most of these were named by the earlier visitors to the Park, who christened the Giant, Bee Hive, Old Faithful, and other equally familiar geysers.

Even this brief description of the Upper Geyser Basin is incomplete without some mention of the brilliant colors noticed wherever the hot waters flow. These multitudinous tints of red and yellow,

green and brown, are all produced by the growth of hot-water algæ, which, as I shall show further on, eliminate silica from the hot waters by their vital growth, and contribute largely to the building up of the sinter deposits, besides giving them their brilliant tints.

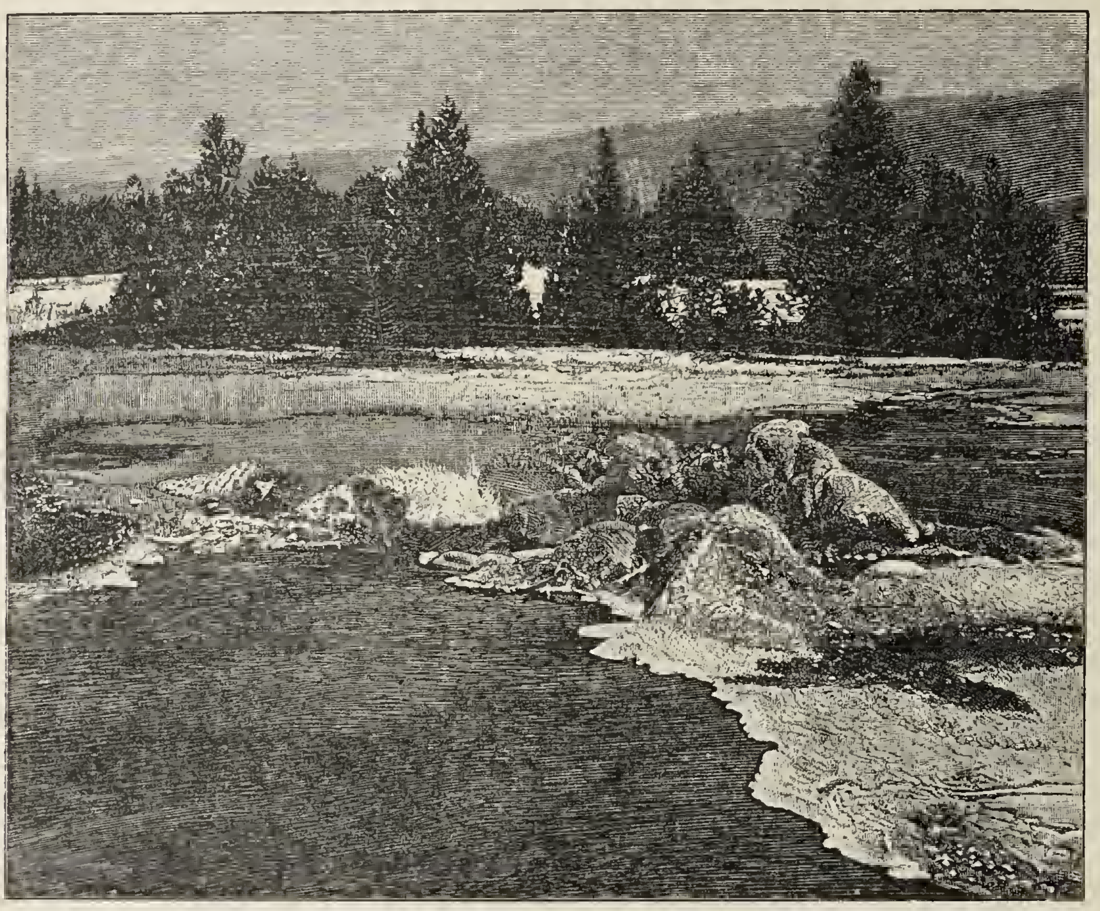

Fig. 55. Avoca Spring, Upper Geyser Basin.

## CHARACTER OF THE HOT SPRING WATERS.

The hot waters of the Upper Basin are mostly clear and perfectly transparent and show in perfection the blue-green tints of pure water in the many spring bowls and basins. In many of the springs an iridescent effect is seen in the water, which is not due to a film on the surface, but is caused by the reflection of light from circulating currents. Tested with litmus paper, the water is either neutral or feebly alkaline in reaction, and it generally possesses a slight sulphurous odor. When cold it is flat and insipid in taste and scarcely palatable, but is not injurious. These alkaline-siliceous waters are similar in character but vary slightly in the amount of material held in solution. Chemical analysis shows this to consist of silica and of readily soluble alkaline and earthy salts, which are retained in solution and carried off by the surface drainage, while a large part of the silica is deposited about the springs and geysers.

The following analyses, made for the Geological Survey of the Park by Prof. F. A. Gooch and J. E. Whitfield, show the composi-

tion of the geyser waters of this basin. Analyses are also given of the water from the Great Geyser of Iceland, and from the New Zealand geysers, the former by Damour,[1] the latter by Smith.[2]

*Analyses of geyser waters.*

[Constituents grouped in probable combination. Grammes per kilogram.]

| | Asta Spring. | Splendid Geyser. | Grand Geyser. | Old Faithful Geyser. | Great Geyser, Iceland. | White Terrace Geyser, New Zealand. |
|---|---|---|---|---|---|---|
| $SiO_2$, silica | .1650 | .2964 | .3035 | .3961 | .5190 | .6060 |
| $NaCl$, sodium chloride | .1320 | .4940 | .5643 | .6393 | .2379 | 1.6220 |
| $LiCl$, lithium chloride | .0048 | .0140 | .0218 | .0340 | .......... | *.0950 |
| $KCl$, potassium chloride | .0221 | .0231 | .0319 | .0478 | .......... | ........ |
| $KBr$, potassium bromide | ........ | ........ | Trace... | .0051 | .......... | ........ |
| $Na_2SO_4$, sodium sulphate | .0575 | .0281 | .0387 | .0270 | .1342 | ....... |
| $Na_2B_4O_7$, sodium borate | .. ...... | .0335 | .0350 | .0213 | .......... | ........ |
| $Na_2AsO_2$, sodium arseniate | ... .... | .0025 | .0014 | .0027 | .......... | ........ |
| $Na_2SiO_3$, sodium silicate | ........ | .......... | .......... | .0279 | .......... | †.2290 |
| $Na_2CO_3$ sodium carbonate | .1463 | .5286 | .3209 | .2088 | .2567 | ........ |
| $MgCO_3$, magnesium carbonate | .0035 | .0018 | None ... | .0021 | .......... | Trace. |
| $CaCO_3$, lime carbonate | .0295 | .0075 | .0070 | .0038 | ... .... . | .025 |
| $FeCO_3$, iron carbonate | ........ | .0001 | ....... ... | Trace... | .......... | ........ |
| $Al_2O_3$, alumina | .0112 | .0051 | .0061 | .0017 | .......... | .005 |
| $H_2S$, hydrogen sulphide | ........ | .......... | Trace... | .0002 | .......... | ........ |
| $NH_4Cl$, ammonium chloride | ........ | .0002 | .0012 | Trace... | ...... ... | ........ |
| $CO_2$, carbonic acid | .1045 | .1989 | .0587 | ......... | .......... | ........ |
| $K_2SO_4$, potassium sulphate | ........ | .......... | .......... | .......... | .0180 | .0750 |
| $MgSO_4$, magnesium sulphate | ...... . | .......... | .......... | .......... | .0091 | ........ |
| $Na_2S$, sodium sulphide | ........ | .......... | .......... | .......... | .0088 | ........ |
| Total | .6764 | 1.6340 | 1.3905 | 1.3908 | 1.2305 | 2.6570 |
| Specific gravity | ....... | 1.00132 | 1.00108 | 1.00096 | 1.000205 | 1.00077 |

*$CaCl_2$ †$Na_2O$.

FORMATION OF SILICEOUS SINTER.

The separation and deposition of silica from hot spring waters in the form of siliceous sinter has been ascribed by different writers to one or more of the following causes :

(1) Relief of pressure.
(2) Cooling.
(3) Chemical reaction.
(4) Evaporation.

At the Norris Geyser Basin the first two causes produce a separation of silica from the hot waters, but the waters of the other geyser basins contain very much less silica, and as far as observed neither relief of pressure nor cooling will produce a separation of the silica. Water collected from the springs and geysers of the Upper and Lower Geyser basins was perfectly transparent, and remains clear

[1] Ann. Chem. u. Pharm., vol. 62, 1847, p. 49.
[2] Jour. für prakt. Chemie, vol. 89, 1863, p. 186.

and without sediment after standing several years. Experiments in the laboratory show that the silica in these waters remains dissolved even when the water is cooled down to the freezing point, and it is only after the crystallization of the water by freezing that the silica is separated and settled down as an insoluble flocculent precipitate upon melting the ice.

The formation of sinter by the waters of the Iceland geyser, which analysis shows to be similar to the waters of the Upper Basin in character, but more heavily charged with silica, is explained by Damour[1] and Descloiseaux by supposing the silica to be present in solution, as an alkaline silicate, which is decomposed by uprising sulphurous and hydrochloric vapors into free hydrated silica and alkaline salts. From the supersaturated solution of silica, formed in this way the silica separates out in the form of sinter. In several analyses, Damour found a constant relation of 3:1 between the oxygen of the silica and that of the bases; when the alkalies are present partly as chlorides and sulphates, formed by the decomposition of the alkaline silicates, the relation existing between the oxygen of the silica and that of the bases of the undecomposed silicates was found to vary from 1:5 to 1:9, and wherever the latter proportion prevailed, as it does in the water of the Great Geyser, silica is deposited, the amount deposited each day corresponding to the quantity of the alkali saturated in that time by the action of the acid vapors or by the oxidation into sulphates of the alkaline sulphides in contact with the air. Laboratary experiments show that the waters of the Upper Basin remain unaltered upon saturating them with hydrogen sulphide, and that the silica is probably present in solution as free hydrated silica.

LeConte and Rising[2] suppose the precipitation of silica taking place at Sulphur Bank, Cal., to be due to the neutralization of the upcoming hot alkaline waters by descending acid solutions, a process evidently not in operation at the geysers of the Upper Basin.

Roscoe and Schorlemmer[3] state that the alkaline silicates of the Iceland waters are decomposed by the carbonic acid of the atmosphere with a formation of alkaline carbonates and free silica, the latter being deposited. This gas, passed through the Upper Basin waters for several hours, produced no visible effect upon the water. Bunsen, to whom we are indebted for the accepted theory of geyser action, ascribed the formation of the Iceland sinters to the evaporation of the water.[4] His experiments showed that the silica of the geyser water was not deposited upon cooling and only separated out upon the advanced concentration of the water, but was readily de-

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[1] Philos. Mag., London, 1847, vol. 30, p. 405.

[2] Am. Jour. Sci., 3d series, vol. 24, p. 33.

[3] Treatise on Chemistry, vol. 1, p. 571.

[4] Pseudo-volcanic phen. of Iceland: Memoirs of Cav. Soc., Graham, 1848, p. 336.

ALGÆ CHANNELS, EMERALD SPRING, UPPER GEYSER BASIN.

posited by evaporation. This cause produces some of the siliceous sinter found about the hot springs and geysers of the Upper Basin, but it is to the vegetation present in these hot waters that we must credit the formation of the greater part of the siliceous deposits of the geyser basins.

## ALGOUS VEGETATION OF THE HOT WATERS.

Algæ are found in the thermal waters of the Upper Geyser Basin wherever the temperature is not too high to permit their development. The limiting degree of heat at which they have been found is 185° F., but the algous filaments are often found at that temperature, though such plants are immature and poorly developed, and it is not until the waters have cooled down to a temperature approximating 140° F. that these growths attain their full development. In these cooler waters their vegetable nature is more easily recognizable, for the waving green filaments, or the red and brown leathery sheets lining the springs, closely resemble sea weeds found on our coasts. But in the hotter waters the material hardly suggests the presence of vegetable matter, the densely gelatinous substance resembling mineral or possible cartilaginous animal material. The colors of these growths are generally quite brilliant, either golden-yellow, orange, or red, and in the hottest waters pale flesh-pink, or even white. These algæ are often so thickly encrusted by silica that the plant structure is not recognizable even under the microscope, and their presence is often only to be distinguished by the color. It has been found that the color of the growth depends upon the temperature of the water so that differences in color mark different degrees of heat. Some of the most striking color effects of the Upper Basin are due to this fact, such as the ribbon-like stripes of overflow channels, and the concentric rings of color found in shallow flaring hot spring bowls, and reaching a wonderful development in the Prismatic Lake of the Midway Basin.

The general sequence of colors is well illustrated by the occurrence of such growths in overflow streams with a constant volume, such as the outlet of the Black Sand. As the water from this spring flows along its channel it is rapidly chilled by contact with the air and by evaporation, and is soon cool enough to permit the growth of the more rudimentary forms which live at the highest temperature. These appear first in skeins of delicate white filaments which gradually change to pale flesh-pink farther down stream. As the water becomes cooler this pink becomes deeper, and a bright orange, and closely adherent fuzzy growth, rarely filamentous, appears at the border of the stream, and finally replaces the first-mentioned forms. This merges into yellowish-green which shades into a rich emerald farther down, this being the common color of fresh-water algæ. In the quiet waters of the pools fed by this stream the algæ

present a different development, forming leathery sheets of tough gelatinous material with coralloid and vase-shaped forms rising to the surface, and often filling up a large part of the pool. Sheets of brown or green, kelpy or leathery, also line the basins of warm springs whose temperature does not exceed 140° F., but in springs having a higher temperature the only vegetation present forms a velvety, golden-yellow fuzz upon the bottom and sides of the bowl. This growth is rarely noticed in springs where the water exceeds 160°, except at the edge of the pool. If the basin is funnel-shaped, like that illustrated in Fig. 56, with flaring or saucer-shaped expansion, algæ grow in the cooler and shallower water of the margin, forming concentric rings of yellow, old gold and orange, shading into salmon-red and crimson, and this to brown at the border of the spring. Around such springs the growth at the margin often forms a raised rim of spongy, stiff jelly, sometimes almost rubber-like in consistency, and red or brown in color. Evaporation of the water drawn up to the top of such rims leaves a thin film of silica, which thickens to a crust and so aids in the production of a permanent sinter rim.

Where the overflow from a spring spreads out over the surface of a mound the algæ often grow in cushions of red, white, brown or green jelly, generally mistaken for simple gelatinous silica colored with iron, and indistinguishable from simple mineral material to the naked eye, though the putrid odor of such material removed from the water and allowed to decay indicates its organic nature. In the pools and basins about most of the geysers the bright orange algæ form a velvety nap upon the smooth surface of the sinter. This is easily recognizable in the pools about the Jewel Geyser, but the same growth occurring in the basins about Old Faithful, and very generally in the overflow channels of all the geysers, is so obscured by the silica deposit about it that it is only noticeable because of its brilliant color and the slippery feeling it imparts to the surface.

## ALGÆ POOLS AND CHANNELS.

The vegetation of the hot spring waters attains its maximum development in the self-formed pools and basins found near the Emerald and the Black Sand springs of the Upper Basin and the Jelly Spring of the Lower Geyser Basin. This is largely because of the great and constant volume of the overflow from such springs, taken in the natural water-ways and pools which the algæ form, and distributed by a nicely-adjusted system, by which the continual increase and growth of different parts of the overflow area are promoted and fostered. At such places the formation of sinter by these plant growths goes on rapidly, and the various gradations may be seen, from the soft jelly to the firm and hard sinter, into which it is transformed.

ALGÆ BASIN, EMERALD SPRING, UPPER GEYSER BASIN.

One of the best places to observe such pools is the flat about the Emerald Spring, where the sinter is all of algous origin. The Emerald Spring, whose clear green depths make the name a most appropriate one, is situated on the west bank of Iron Creek, about three-fourths of a mile west of the Upper Geyser Hotel. The bowl is 36 feet wide, 30 feet to 40 feet long, and 35 feet deep, surrounded by a shallow basin or marginal area 1 to 5 feet wide, outlined and rimmed by a low border of firm algous jelly whose upper surface is whitened by silica left by evaporation. The water is apparently perfectly clear and free from suspended material, and it possesses a temperature of 150° in the spring bowl. The bottom and sides of this bowl are formed of a creamy gray siliceous mud, particles of which are probably held in suspension in the water. This is covered by a fuzzy growth of light canary-yellow algæ. This coloration is best seen near the edge of the bowl, though in the shallower water of the margin the color is deeper, and in the recesses where the temperature is but 135° F. the growth is brownish-green at the surface, underlaid by bright red, and forms a soft, leathery sheet on the bottom.

The overflow of the spring is very uniform in volume, and leaves the basin at the southwest end, running off in a channel 2 to 4 feet wide and half an inch to 2 inches deep. This channel is lined with a thin membraneous sheet, whose gamboge yellow shades gradually into a yellowish green, with dull red, and olive greens at the borders of the stream. Twenty feet from the outlet the stream broadens into an area of algæ channels and basins, outlined and dammed up by the algous growth. Pl. LXXXII shows a portion of this area, photographed after draining off the water. In the foreground is the water-way, inclosed by the algous growth at the sides, its floor dotted with insular masses of the same material, the normal water level being up to their tops. In the background is seen a part of the surrounding flat with dead tree trunks standing upright in the sinter, their lower portions white with silica left by the evaporation of water drawn up by capillary force. The algous forms seen in this illustration are quite characteristic of the growth where the conditions permit its full development. This water-way is floored with a sheet of olive or emerald green, kelpy jelly. Where there is a moderate current this lining is nearly smooth, resembling a sheet of wet leather, but in quieter water this soft carpet is dotted with warty excrescences and little pillars produced by their upward growth ; the latter sometimes terminates by balloon-like caps or globes containing a bubble of gas. When in the early stages of their growth these slender spines or pillars consist of soft gelatinous material, sinking to a shapeless mass of jelly when removed from the water, but as they increase in height and in diameter a firmer siliceous center is formed which gives stability to such shapes. When by their upward growth these pillars reach the surface of the pool they increase

rapidly in diameter, particularly at the water level, and a cup-shaped cap or crown is soon formed upon the pillar, often with a vase-like shape. If several of these grow near together the caps extending laterally soon unite, and form the peculiar masses seen in Pl. LXXXII. The continued growth of new pillars gradually fills up parts of the channel and eventually pond back the water, partially at first and at last entirely. In this case the increased depth of water resulting permits a further upward growth of the algæ, and a series of pools or basins sometimes results, in which the water levels are quite different, while the water cooled in passing from pool to pool possesses different temperatures in each. A close view of such a basin is shown in Pl. LXXXIII, part of the same area shown in Pl. LXXXII. The algous growth has here dammed up a channel forming a little basin already partly filled with isolated pillars and aggregates these growths. The continued growth of the algæ raises the water of level until finally the enfeebled current brings but a small supply, with a consequent gradually lowered temperature, not only for the basin itself, but also in adjacent pools whose supply may have been entirely cut off. In such cases, the nature of the growth changes; it is not known that life ceases, though it seems probable that these algæ die, and new species are introduced. At any rate, the bright-colored algous jelly forming the outer covering of the pillars and algæ vases changes to light salmon pink, and the substance itself becomes noticeably siliceous or forms a filmy web upon the siliceous center. There is as yet no increment of silica, but a simple shrinking and hardening of the gelatinous envelope, but if the temperature be gradually reduced to 85° F. or 90° F. these forms become coated with a mossy incrustation of hard silica, and the algous structure and outlines are obscured or concealed by the coral-like coating.

If instead of this gradual reduction of the volume and temperature of the supply, the water is completely shut off suddenly, the gelatinous material dries up, for the water in the basin either evaporates or oozes through the porous growth. In this case the algæ soon lose their bright colors, which fade like those of the Mammoth Hot Springs to a delicate salmon pink, and finally pure white, becoming light but firm structures of opaque white, hydrated silica. Generally the pools have been filled up by the pillars, and oftentimes completely roofed over by their tops, before the desiccation of such areas leaves them a bare white flat. In many parts of the Upper Basin, the crust or surface of the sinter flats can be broken through, exposing a structure that makes the origin of the deposit at once apparent to one familiar with the algous forms of hot water pools.

A number of simple experiments were made with the overflow of the Emerald Spring to determine, first, the rapidity with which the algæ establish themselves in new overflow channels, and secondly,

UPPER ALGÆ BASIN, JELLY SPRING, LOWER GEYSER BASIN.

the effect of a diminished supply and of temperature upon existing growths, and the final death of the algæ when the water is completely shut off. Cutting an outlet in the margin of the spring the outflow ran over a surface of compact, hard and dry sinter. On the second day this surface showed a very faint yellowish coloring; the third day this was easily noticed, and occurred in patches and not uniformly over the surface. Two weeks later, the greater part of the overflowed area was covered with a fuzzy golden-green growth, which was coherent and membraneous in a few places, but which as yet showed no traces of the pillars and related forms found in the old basins. Where the rim of the spring had been cut, a shallow recess had permitted a partial cooling of the water, and an olive-colored, leathery sheet covered the floor. The current resulting from the overflow, immediately raised the temperature above this growth, which soon looked blistered and pale, and changed in the course of a few days to pale, yellowish green. Reducing the supply of the algæ channel and pools (Pl. LXXXII.) caused no change in the growth still covered by the water, in the first two days, but that portion of the growth left exposed to the sun soon began to dry and shrink. In twenty-four hours the dark emerald green of the leathery sheets had changed to dark purple, and where driest to black with a shining metallic luster. In drying, the siliceous jelly shrank considerably, and in consequence the surface layers had curled up in irregular patches, exposing the underlying layers of crimson jelly. No odor was yet perceptible, but flies gathered thickly upon many parts of the decomposing vegetation. In those pools, where growth had previously ceased, the algous forms were rapidly drying, the pink tint fading, and the more delicate parts already white and dry.

On the third day the surface layer of the leathery sheets was still more cracked up, the patches curled, with their edges white and dry, the underlying red jelly drying to rose pink, while the odor of decaying organic matter was strong and repulsive. The lowered temperature of the water had now effected the growth beneath it, and the olive and green flow showed patches of reddish brown, pink, and deep green. The supply of water being restored to portions of the water-way, the growth did not recover as rapidly as was expected. The lustrous black of the decaying vegetation changed in the course of a few days to spotted purple patches, but the red layers, still exposed, changed to salmon. There is no doubt that if the water supply had not been restored the colors would have gradually faded out, leaving a white area of siliceous material as light as cork, where formed from the soft and jelly-like algæ, but heavier and denser, where the older forms had grown, this being the result at other places where similar pools are found.

If specimens of the different varieties of the growth be removed from the water and allowed to dry rapidly, the jelly contracts greatly

in drying, the air-dried material being about one-third the bulk of the moist jelly. The gelatinous coating of the pillar and vase-shaped forms curls up in thin flakes, whose outer surface retains the color of the growth, exposing the light flesh-colored siliceous frame-work of the algæ.

The tendency of the algous growths to form terraced basins is beautifully illustrated in the basins supplied by the waters of the Jelly Springs at the base of the mound of the Fountain Geyser. In these basins the different stages of sinter forming are sharply drawn, from the soft and brightly colored jelly to a hard and stony sinter.

Pl. LXXXIV shows the uppermost of these basins; the dam ponding back the water is about a foot high, and is formed of a fibrous sinter, hard and stony below, but grading into a softer material of cheesy consistency above, passing into red and green algous jelly. The algæ of this pool or basin are brightly colored, and the forms resemble those of the Emerald Spring, but the pillars are taller, owing to the greater depth of the water.

In a lower basin, shown in Pl. LXXXV, the water is nearly cold, and though the forms are the same as those found in the basin above there is no trace of the red, yellow, and green algous jelly. A close view of the forms found in this basin is given in the cut (Fig. 56). In the basin, while covered by water, these peculiar structures are light pink, but they become white upon drying. The tops of the forms shown in the illustration are margined and capped by a very thin film of silica left by evaporation, and the small share which that agent takes in the formation of these deposits is shown in the relative proportion of this edging to the mass of pillars.

Pl. LXXXVII shows two of the forms from the basin figured in Pl. LXXXV. Fig. 1 is one of the finger-like pillars, which do not reach to the surface of the water. The specimen is six inches high and an inch in least diameter. The pure white surface is lined by little knife-edge ridges and dotted with spiny points of silica, all hung with small patches or shreds of a delicate web or film of silica, the remains of the algous jelly that once covered the surface. A transverse section shows the specimen to consist of a central core of white siliceous layers in the form of very thin concentric sheets or cylinders, surrounded by a loose wrapping of similiar paper-like sheets. The outer surface is hard, but brittle and easily broken. Such finger-forms frequently occur in clusters, sometimes of very different heights, and several often coalesce as they grow upward, and produce little pinnacled shapes. As already stated, in describing the algæ of the Emerald Spring, these pillars continue their upward growth when the algæ are living until their tops reach the water level, when, if the plant growth continues, a spreading top is formed, upon which evaporation leaves thin films of pearly silica.

One of the smallest of these curious, stony yet vegetable forms, is

MIDDLE ALGÆ BASIN, JELLY SPRING, LOWER GEYSER BASIN.

shown in Fig. 2, Pl. LXXXVII. The specimen figured is eight inches high, and shows in its graceful curves the bending of the original gelatinous material before the current of the basin. The broader base of the specimen is made of smaller spiny forms growing together and united to the base of the pillar. Above the middle the column expands into a hoop-shaped mass, crowned by irregular bands of pearly sinter. This specimen is also lined by the little ridges so prominent in the first figure, though they are much less noticeable and scarcely show on some parts of the specimen. Such forms reveal quite clearly their algous origin, but the stony masses found in a lower and empty basin, shown in Pl. LXXXVI, are apparently quite different in nature, though formed by the incrustation of the shapes shown in Fig. 56. This basin is the lowest of the series, and if some

FIG. 56. Algæ forms, Lower Geyser Basin.

cause had not operated to produce the death of the algæ, and an incrustation of the structures, before the filling up of the basin with their siliceous stems, the basin would now form only a bench, indistinguishable from the rest of the sinter flat above it. Fig. 3, Pl. LXXXVII, shows a specimen taken from this basin; the transverse section proves it to consist of a central form similar to Fig. 2, Pl. LXXXVII, covered with a mossy coating of silica, three-fourths of an inch thick, which rounds off and hides the outlines of the incrusted pillar. This coating has a rough coral-like surface, with clustered knobs of silica, which a lens shows to consist of delicate spicules of glassy sinter. The deposit is firm and hard, and the aggregated masses form a compact and solid sinter.

In the pools supplied by the Black Sand Spring, which are collectively known as Specimen Lake, the algæ are exactly like those described, save that they are generally slimmer and taller, often twelve or fifteen inches in length, and their tops, uniting, form a solid roof, often in turn the floor of a new basin, with a new growth of algæ. The pillars rarely grow solidly and closely together, so that specimens of the sinter are coral-like, the pillars coated with an efflorescent granular coating of silica. The desiccation of such areas leaves a deposit of sinter whose surface shows no trace of its origin and of the beautiful forms beneath, and such deposits occur in many places about the Geyser Basin.

The exact manner in which the algæ of these waters eliminate the silica from solution is not known, but the process appears to be due to the vital growth of the plant, for both the algæ filaments and their slimy envelope are formed of gelatinous silica. Upon the death of the algæ which have separated this jelly from the spring waters, there is a loss of a large part of its water, and a change to a soft, cheesy, but more permanent form. This dehydration is carried still farther if the silica be removed from the water and dried, but if allowed to remain in the cold water pools there is a further separation of silica, possibly due to organic acids, formed by the decaying vegetation reacting upon the silica salts of the water; this hardens the existing structures, in certain cases, and generally covers the pillars with a frost-like coating of silica.

In general, it may be stated that the large vase and pillar forms found in the algæ pools can be produced only by a concurrent life and death of these plants, the outer layers continually growing, the innermost dying. This is readily seen to be the cause of the peculiar structure of these forms. The central core is a pillar, sometimes hollow, sometimes solid, consisting of exceedingly thin superimposed layers of silica, each of which corresponds to a layer of algæ jelly, which has become hardened by the death of the plants and the loss of water. The column increases in diameter by the growth of the algæ at the surface, and a simultaneous death and hardening of the

STONY FORMS IN JELLY SPRING, LOWER GEYSER BASIN.

inner layer of jelly. The algous envelope consists of two, three, or more thin membraneous layers, the outer, green, the inner, tomato red, these layers corresponding to the laminæ of the hardened inner core. The slimy, leathery sheets, so common in the cooler springs (100° F. to 135° F.), are similar in nature, and when dried are thin crusts of light, corky sinter. Another form, abundant about the Solitary Spring, where it has built up a sinter mound of considerable magnitude, consists of cushion-like masses of jelly, sometimes six inches thick, which, if removed and dried, shrivel up to less than half that thickness, and are exceedingly light and porous, floating on water. The under layer of such thick masses is decaying and changing to sinter, into which it can be traced in situ.

## FIBROUS VARIETIES OF ALGOUS SINTER.

Besides the varieties of sinter formed by these vegetable jellies, there are two kinds of fibrous sinter, very abundant about some of the hot springs, and constituting an important part of the sinter deposits. The first, forming in the overflow channels of many of the geysers of the Upper Basin, is finely fibrous, consisting of layers one-sixteenth of an inch to half an inch thick, each stratum resembling a very fine thick white fur. This sinter is formed by the growth of the little algæ—*Calothrix gypsophila* Kg.—or the young form, *Mastigonema thermale,* the latter olive-colored and forming the sinter alluded to later in the section of the sinter walls of the crater of the Excelsior Geyser. The second form is fibrous, and occurs in rough, straw-like masses, with thatched arrangement. A coarse variety is due to a bright red species of algæ—*Leptothrix*—a finer variety to *Leptothrix* (or *Hypheothrix*) *laminosa,* a species found from 135° to 185° F., and ranging in color from white to flesh, pink, yellow, and red to green, as the water cools. The specimens determined came from the mounds of Sentinel Creek.

The proportion of algous sinter forming the deposits about the Geyser Basins is strikingly shown in the following section of the strata forming the wall of the Excelsior crater:

| | Inches. |
|---|---|
| 21. Uppermost layer, fibrous, "furry" sinter | 15 |
| 20. Cemented, sinter fragments | 0.5 |
| 19. Fibrous sinter, brownish colored | 3 |
| 18. Thatch-like, fibrous sinter | 0.5 |
| 17. Cemented fragments | 3 |
| 16. Thatch-like sinter | 3 |
| 15. Fibrous | 2 |
| 14. Cemented fragments | 1 |
| 13. Thatch-like | 12 |
| 12. Same, mixed with cemented material of same nature | 2 |
| 11. Fibrous, 9 layers ¼ inch to 1 inch thick | 6 |
| 10. Cemented fragments, partly of organic origin | 6 |
| 9. Fibrous | 2 |

| | Inches. |
|---|---|
| 8. Flaky sinter formed by algous sheets | 4 |
| 7. Fibrous and thatch-like, about equally divided | 36 |
| 6. Fibrous | 2 |
| 5. Flaky, pearly, algous | 3 |
| 4. Thatch-like, brown | 10 |
| 3. Fibrous, 10 to 20 layers | 8 |
| 2. Cemented material | 8 |
| 1. Fibrous | 12 |
| | 11 ft., 6 ins. |

In this section fifty per cent. consists of the fibrous sinter formed by *Mastigonema*, 36 per cent. (4 feet, 2 inches) of the thatch-like or flaky sinter formed by the membranous algæ, *Leptothrix* ——.

The crater wall nearest the Prismatic Spring is 15 feet high, and the sinter may be thicker, as the underlying material is not exposed. This sinter, which forms a plateau covering many acres, has been formed by the vegetation nourished by the overflow from the Prismatic Spring, and the older layers have a terraced surface exactly like that of the deposit now forming about this spring.

## RATE OF DEPOSITION OF SILICEOUS SINTER.

The pearl-beaded, coralloid forms of sinter found about spouting vents are formed very slowly. In one case, where the signatures of a party who visited the geysers in 1879 are known to be authentic, the pencil marks are covered by a glaze of silica but $\frac{1}{120}$ of an inch thick, or an increase of $\frac{1}{1080}$ of an inch a year, and this where the conditions for the formation of sinter by evaporation are quite favorable.

The difference between the rate of deposition of geyserite by these waters and those of the Norris Basin, notably by the water of the Opal Springs Coral, is shown by the fact that at the Opal Spring an incrustation of one-quarter of an inch formed in three weeks.

Other names, written upon the salmon-colored channels running into the Firehole, near the Castle and Saw-Mill geysers, show a growth of $\frac{1}{200}$ of an inch to $\frac{1}{60}$ of an inch a year, but this rate is effected by the combination of very favorable conditions for evaporation and the presence of algæ.

The fibrous sinters forming the flow of the geyser channel are composed of layers from $\frac{1}{40}$ to $\frac{1}{10}$ of an inch thick and averaging $\frac{1}{20}$ of an inch. If they represent a year's growth, and the evidence favors that view, the line of glassy silica separating them being formed during the winter, then the rate is $\frac{1}{20}$ of an inch a year.

On the other hand, the thick masses of jelly found in some of the overflow areas may form sinter with comparative rapidity. Thus the channel of the Beauty Spring, which contained no water in 1887, was filled with a growth of vegetable jelly 5 inches thick in 1888,

Fig. 1.

Fig. 2.

Fig. 3.

SINTER FORMS FROM ALGÆ BASINS.

nourished by the largely augmented overflow of the spring. A mass of this was cut out when the place was visited in July, and upon the sinter a new growth 1⅛ to 1¼ inches thick had formed by October, seventy-three days' growth, while areas of what had been bright colored jelly in July had diverted the water by their growth, and were now hardened and pink, and rapidly passing into firm and solid sinter.

### MICROSCOPIC EVIDENCE.

A microscopic examination of specimens collected at the Beryl Spring, Gibbon canyon, shows that the fibrous, asbestos-like material consists of minute tubes of glassy transparent silica corresponding to the filaments of the growing algæ. In this case the filaments appear to have been free from the enveloping jelly, which dries to an opaque white silica and hides the filaments and rods of most growths.

Thin sections of siliceous sinters fail to show the origin and nature of the deposit as clearly as had been hoped. A section of dried algous jelly from the Emerald Spring shows innumerable interlaced and interwoven filaments, with some glassy silica between. A hard fibrous sinter, formed by the long filamentary growth of an overflow channel, shows only traces of the algæ filaments under the microscope, but consists very largely of minute globules of glassy silica, varying somewhat in size and corresponding to those forming the cells of the algæ. These are held together in a cementing matrix of glassy amorphous silica. Thin sections of a sinter formed of broken fragments of algæ pillars, cemented into a firm hard sinter, shows a similar structure.

If many of the algous sinters fail to reveal an organic structure beneath the microscope, they are nevertheless easily distinguished from the more glassy and pearly sinters formed by evaporation. A thin section of a sinter from the Solitary Spring, Upper Basin, shows in marked contrast the numerous and extremely thin overlapping layers of lustrous pearl sinter formed by evaporation and the duller chalky white of the algous formation.

### MOSS SINTER.

Besides the deposits of siliceous sinter formed by the algous vegetation of the hot waters, extensive deposits of sinter are found on the slopes below the Hillside Springs, which are due to the growth of mosses. These springs issue from the rhyolite slopes beneath the cliffs of the Madison Plateau, and the waters, whose temperature is 184° to 198° F., contain both silica and lime in solution, which they deposit in their downward flow. On the lower part of the slopes the water is cooled to blood heat, and has lost much of its lime and part of its silica. This part of the slope is terraced with basins sug-

gesting those of the Mammoth Hot Springs, but covered with a bright green growth of moss. These basins are formed of a porous yellow sinter, full of moss stems, and often consisting entirely of these plant structures.

Chemical analysis shows this substance to be a true siliceous sinter (see analysis, p. 670). This sinter is not formed by evaporation, nor by any of the causes discussed in considering the precipitation of silica from solution, but it is due to the abstraction of silica from the water by the mosses covering the surface of the basins. This moss has been determined by Prof. Charles R. Barnes, of the University of Wisconsin, to be *Hypnum aduncum* var. *grasilescens* Br. & Sch.

### DIATOM BEDS.

Besides the elimination of silica from the hot-spring waters by the algous growths living in them and by the mosses of the cooled water, there is a further secretion of that substance by several species of diatoms which live in the tepid waters of the hot-spring marshes, and, though they do not form siliceous sinter, their remains accumulate as beds of diatom earth that are often of great thickness and width.

It is well known that the single-celled algæ, called diatoms, possess in a remarkable degree the power of separating silica from solution to form the beautifully marked siliceous armor of the plant. In the ocean waters this action is the more remarkable because of the exceedingly small proportion of silica found in solution in the water, and the almost incredible activity necessary on the part of the plant to secure an adequate supply. As the silica of such dilute waters is not separable by any known chemical process, its elimination must needs be credited to some vital process of the plant growth, and it is this action which gives to this low form of life its importance as a geological agent. As the *Diatomaceæ* exist under very diverse and extreme conditions of environment, occurring in nearly every country pond and stream, as well as the icy waters of Polar seas, the heated currents of the tropics, and even the almost boiling waters of hot springs, we are not surprised to find them existing also in the siliceous waters of the Yellowstone Springs, which, indeed, seem peculiarly adapted to the needs and growth of these little plants. Investigation shows, however, that while diatoms occur in the ponds of the hot-water algæ, whose occurrence has already been described in detail, yet they are only found in abundance in the cooled, tepid waters of the springs. In such waters they are exceedingly abundant, and form the ooze of which the marshes of the geyser basins are so largely composed.

A typical marsh of this character is found near the beautiful Emerald Springs of the Upper Geyser Basin. A large part of this marsh is covered with a sparse growth of rushes and brackish-water vegetation, which of course is gradually filling it up and convert-

ing the bog into a fairly firm, grass-grown meadow bottom. But the greater area is at present quite wet, and its treacherous ooze and apparently bottomless depths will be long remembered by those who have ever tried to cross the marsh.

The waters of this area have in times past encroached upon the neighboring patch of timber, killing the trees, whose bare gray trunks stand upright in the ooze or lie scattered about and half immersed beneath the surface. A subsequent partial recession of the water has left a bare white strip between bog and woods, on which vegetation has as yet a precarious foothold, and the gaunt, bare poles of the dead pines rise up from a barren, powdery, white soil, evidently a dried portion of the marsh mud. The semi-liquid ooze of which the marsh consists proved upon examination under the microscope to be composed of the beautiful siliceous tests of various species of these minute plants. Samples of this material, which Dr. Francis Wolle, of Bethlehem, Pa., has kindly examined for me, were found to contain the following species:

| | |
|---|---|
| Denticula valida Ped. | Achranthese. |
| D. elegans. | Cocconema. |
| Navicula major and N. viridis. | Fragilaria. |
| Epithemia (three species). | Eurotia. |

The first-named species, *Denticula valida*, formed the bulk of the specimen, and also of the white pulverulent material at the margin of the bog, which microscopic examination showed to be the dried remains of the same diatoms. Samples from many other marshes of this character were examined and found to be formed of the same species.

The extensive meadows of the Lower Geyser Basin, the Norris Basin, Geyser Creek, and many other places are underlaid by beds of diatom earth composed of these same species, and where the wagon-road crosses these areas the ditches made alongside the road for drainage exposed the beds, while square blocks of the dried diatom earth lie scattered about at the side of the road. These and similar meadows are many square miles in extent, and the diatom beds are often two to three, and sometimes six to seven feet thick. Not seldom the meadows and diatom marshes overlie ancient hot-spring areas, the sinter flats and even the hot spring mounds and cones being completely covered and hidden by the covering of diatom ooze.

## NATURE OF SILICEOUS SINTER.

Siliceous sinter, the siliceous deposit of thermal waters, is a variety of opal, occurring as a grayish white, or brownish incrustation about hot springs. Slightly different varieties have been described under different names: a pearly lustered specimen from Santa Fiora, Italy, being called Fiorite by Thompson; a filamentary sinter from

St. Michael, Azores, described as Michaelite; while the Iceland and New Zealand sinters are known as geyserite.

Siliceous sinter varies much in appearance and in structure, according to its manner of formation; it is sometimes earthy and crumbly, often finely laminated and shaly or light and porous, occasionally fibrous or even filamentous, and rarely compact and flinty. It is generally opaque, though often possessing a vitreous luster, and rarely translucent, and it grades into hydrophane and hyalite by alteration. The batryoidal and coralloidal forms are generally found only about the mouth of geysers and steam vents, and are usually more compact and translucent than other varieties. The sinters produced by algæ are generally very light, with an open, porous, almost cavernous structure, but this is often altered to hard opal sinter by infiltering water. The following table shows the composition of a number of Yellowstone sinters, with the analyses of Michaelite and the Iceland and New Zealand geyserites added for comparison:

*Analyses of Yellowstone sinters.*

| | I. | II. | III. | IV. | V. | VI. | VII. | VIII. | IX. | X. |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$, silica | 89.54 | 81.95 | 93.88 | 93.37 | 89.72 | 87.67 | 82.29 | 86.03 | 92.67 | .... |
| $Al_2O_3$, alumina | 2.12 | 6.49 | 1.73 | 1.16 | 1.02 | 0.71 | 1.36 | 1.21 | 0.80 | .... |
| FeO, ferrous oxide | Trace. | Trace. | 0.14 | Trace. | | | Trace. | | | |
| CaO, lime | 1.71 | 0.56 | 0.25 | 0.29 | 2.01 | 0.40 | ........ | 0.45 | 0.14 | .... |
| MgO, magnesia | Trace. | 0.15 | 0.07 | 0.05 | Trace. | ........ | ........ | 0.40 | 0.05 | .... |
| $Na_2O$, soda | 1.12 | 2.56 | 0.28 | 0.11 | ........ | 0.82 | ........ | 0.38 | 0.18 | ... |
| $K_2O$, potash | 0.30 | 0.65 | 0.23 | 0.02 | ........ | Trace. | ........ | | 0.75 | .... |
| $SO_3$, sulph. acid | Trace. | 0.16 | 0.20 | 0.31 | Trace. | ........ | ........ | ........ | ........ | .... |
| Cl, chlorine | Trace. | Trace. | ........ | ........ | ........ | ........ | ........ | ........ | ........ | .... |
| NaCl, sodic chloride | ........ | ........ | 0.18 | 0.08 | ........ | ........ | ........ | ........ | ........ | .... |
| Organic matter | ........ | ........ | ........ | 1.50 | ........ | ........ | ........ | ........ | ........ | .... |
| $H_2O$, water | 5.13 | 7.50 | 3.37 | 4.17 | ........ | 10.40 | 16.35 | 11.52 | 5.45 | .... |
| Total | 99.92 | 100.02 | 100.33 | 100.41 | 100.09 | 100.00 | 100.00 | 99.99 | 100.04 | .... |

No. I, is a compact white sinter from the mound of Old Faithful.

No. II, is a grayish sinter from the margin of Splendid Geyser.

No. III is a light porous algous sinter from Solitary Spring.

No. IV is the analysis of a dried specimen of jelly from Emerald Spring.

No. V is the moss-sinter from Asta Spring, Hillside Group.

These analyses were all made by Mr. J. E. Whitfield for the Geological Survey of the Yellowstone National Park.

No. VI is the analysis of Michaelite from the Azores, by Webster.[1]

No. VII is a geyserite from the mound of the Great Geyser of Iceland,[2] by Damour.

[1] Webster, Am. Jour. Sci., 1st series, 1821, vol. 3.

[2] Bull. Soc. Geol. de France, 2d series, 1848, vol. 5, p. 160.

No. VIII is a hard white sinter from the White Terrace, New Zealand, Mayer.[1]

No. IX is a white sinter from Steamboat Springs, Nevada, analyzed by Woodward.[2]

Analysis No. I shows the composition of a sinter in which evaporation and algous growth both cause the separation of the silica. The sinter from the Splendid Geyser, whose analysis is given in No. II, is a deposit formed without the aid or presence of plant life, wholly by the evaporation of the geyser water. The interior of the specimen is composed of irregular crinkled laminæ of greenish gray sinter, some of it possessing a nacreous lustre; this is covered by light gray fibrous sinter, the fibers short and perpendicular to the surface, and resulting from the growth of little spicules. The gray color is due to the impurity present, the analysis showing a comparatively large amount of alumina and soda, with a low percentage of silica. This is probably due to muddy sediment contained in the geyser water, which is left with the silica upon evaporation. The sinter from the Solitary Spring, No. III, is white, opaque, and very light and porous. It is the sinter resulting from the desiccation of an area of algous jelly, such as that abundant about this spring, and was produced by natural causes. Analysis No. IV shows the composition of a specimen of the algous jelly found at the Emerald Spring, removed from the water and dried in the sun. The siliceous residue of this jelly is light pink in color, very buoyant, floating readily upon water, and somewhat hygroscopic. The air-dried material lost 2.7 per cent. of its weight when dried at 100° C.

Analysis No. V is of the straw-colored moss sinter from the basins of the Asta Spring. The structure of the moss is perfectly preserved, and much of the sinter is composed entirely of the moss stems; but other parts have the space between filled with friable white silica, with occasional botryoidal concretions of light gray opal.

The analyses show the greater purity of the sinters formed by algæ, such sinters having less alumina and alkalies, a lower percentage of water, and a correspondingly larger amount of silica. This greater purity is probably to be explained by the fact that the silica of such sinters has been extracted from the water by the vital growth of the plants, while sinters formed by evaporation contain a greater or less amount of kaolin, generally carried in minute quantity in suspension by the geyser waters. It is to such earthy impurities that we must ascribe the differences in the analyses of Iceland sinters made by different chemists.

The physical differences in the unaltered sinters formed by evapo-

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[1] Peterm. Geog. Mitt., 1862, p. 266.

[2] Arnold Hague, Geol. Ex. 40th Par., 1877, vol. 2, p. 826.

ration and those of algous origin is generally quite marked, the former being translucent, or vitreous, hard, and heavy, while the algous sinter is opaque, white, and often chalk-like in appearance.

### SILICEOUS SINTERS FROM NEW ZEALAND.

Through the courtesy of Prof. F. W. Clarke, a small collection of siliceous sinters from the hot springs of New Zealand, recently received by the United States National Museum, has been placed at my disposal for examination and comparison with the extensive series of sinters collected by the Yellowstone Park Survey from the hot springs and geysers of that region.

The New Zealand collection, though small, contains examples of many different varieties of this form of opal—the result of diverse conditions of deposition and occurrence. Most of the specimens come from Rotorua, the sanitarium of New Zealand, situated on the southwest shore of the lake of the same name. This locality was long known as Ohinemutu, the name of the Maori village, for the natives of New Zealand utilized the hot waters of these springs for cooking and bathing before the discovery of the islands by Captain Cook. The government, appreciating the therapeutic value of the waters, has leased the ground from the Maoris and erected extensive bathing pavilions and bath pools, where the different varieties of waters may be tried under the direction of a government physician. The place was formerly the starting point for the famous terraces of Rotomahana (the "Warm Lake"), which were destroyed by the eruption of Mount Tarawera in 1886. But Rotorua is itself interesting; the lake is six miles across, with a picturesque island in its center, and surrounded by a chain of blue mountains, while the ponds and wells of hot water and the neighboring geysers of Whakarewarewa are only rivaled by those of the Yellowstone and the famous fountains of Iceland.

The hot springs vary in character from the clear and sparkling, albeit boiling, alkaline siliceous waters of Madame Rachel's Bath, supposed to renew beauty, if not youth, to chocolate-colored and ill-smelling sulphurous pools and strongly acid waters. The following analyses, made by William Skey, the Government analyst, show the character of several types of these waters, the analyses being reduced from grains per gallon to parts per thousand.

*Analyses of New Zealand spring waters.*

| | Madame Rachel's Bath, alkaline, 174° F. | Priests' Bath, strongly acid. | Hot Pool, intensely acid, 200° F. |
|---|---|---|---|
| $SiO_2$, silica, free | 0.0838 | 0.2630 | 0.1957 |
| $Na_2SiO_3$, sodium silicate | 0.2601 | ........... | ........... |
| $CaSiO_3$, silicate of lime | 0.0605 | ........... | ........... |
| $MgSiO_3$, silicate of magnesium | 0.0155 | ........... | ........... |
| NaCl, sodium chloride | 0.9918 | ........... | 0.5210 |
| KCl, potassium chloride | 0.0487 | ........... | ........... |
| $NaSO_4$, sodium sulphate | 0.1685 | 0.2748 | 0.2643 |
| $CaCl_2$, chloride of lime | ........... | ........... | 0.1025 |
| $MgCl_2$, chloride of magnesium | ........... | ........... | 0.0148 |
| $Al_2Cl_2$, chloride of aluminium | ........... | ........... | 0.0617 |
| $CaSO_4$, sulphate of lime | ........... | 0.1058 | ........... |
| $MgSO_4$, sulphate of magnesia | ........... | 0.0432 | ........... |
| $Al_2(SO_4)_3$, sulphate of aluminium | ........... | 0.0395 | ........... |
| $Fe_2(SO_4)_3$, sulphate of iron | ........... | 0.1770 | ........... |
| $H_2SO_4$, sulphuric acid | ........... | 0.3160 | ........... |
| HCl, hydrochloric acid | ........... | 0.0521 | 0.2315 |
| Total | 1.6633 | 1.3821 | 1.3931 |
| Free $H_2S$ | ........... | 0.0425 | 0.1355 |
| Free $CO_2$ | ........... | 0.0308 | 0.0177 |

The alkaline water of Madame Rachel's Bath is said to deposit silica quite rapidly, "a ti-tree twig immersed in the water a week or two resembling a branch of coral,"[1] and the acid waters of the Hot Pool form mineral mushrooms of muddy sinter in the shallow parts of the spring.

It will be noticed that in these analyses the bases have been combined with silica by the analyst, who states that the conditions under which the waters occur are incompatible with the existence of carbonates, though the analyses of Yellowstone waters show that the fixed $CO_2$ of those waters must exist as carbonates.

The siliceous sinters from Rotorua vary from pulverulent deposits of impure silica to dense, white opal sinters. Two of the specimens were evidently formed about spouting vents, showing the peculiar structure and beaded surface produced by the evaporation of spattered drops of water. Such sinters, to which the name of *geyserite* may be most properly applied, are very common about the Yellowstone geysers, occurring often in beautiful coralloidal forms, sometimes possessing a bright pearly luster. The New Zealand specimens are parts of an old deposit formed in this way and consist of numerous little pillars formed of many convex layers of pink and white silica, resembling a pile of minute caps, one upon another. This geyserite is wholly the result of evaporation, which adds film after film of glassy silica to the surface of the deposit, as often as wet by the

[1] J. A. Froude, Oceana, p. 236.

steam or spray from the geyser. An analysis of this sinter is given in the table following (p. 675). Specimens of what may be called incrustation sinter resemble a handful of hay crushed in the hand and coated with white silica. The coarser stalks are hollow tubes with rough and coral-like outer surface with the finer fibers forming gnarled and botryoidal masses. Where the incrusting process has been carried still further the thickened coverings of silica unite and a compact sinter with but small cavities results. Such sinters are also formed by evaporation, on the exposure of the water to the air.

Two of the specimens are of especial interest because their structure indicates that the algous life of the hot waters of Rotorua produced siliceous sinter. This action of hot water algæ has been studied in the waters of the Yellowstone springs and it has been shown that these plants abstract silica from the waters in their growth, forming a mass of jelly which hardens upon the death of the plants, when it is further incrusted by silica precipitated by the decaying vegetable matter. In this way vast areas of sinter, often many feet thick, have been formed in the Yellowstone Park. The specimens from Rotorua show two distinct forms of algous sinter. The first is that produced by membranous sheets of red or green algæ, resembling certain more familiar forms of seaweeds, common not only in the cooler waters of the Yellowstone but in warm waters all over the world, being described as "sheets of a slimy confervoid growth"[2] in the Rotorua waters. This sinter is creamy pink, showing a wavy and very thinly laminated structure with occasional vesicular blisters lined with red and green patches presumably the remains of algæ. It resembles so closely the sinters formed by drying the algous jellies of the Yellowstone springs that a similar mode of formation seems probable.

The second specimen is quite different in structure, consisting of several layers of fibrous silica, the fibers all perpendicular to the layers and resembling a very fine and short, thick, white fur. The exact counterpart of this sinter occurs at many localities in the geyser basins of the Yellowstone, notably about the Prismatic Spring and the overflow channels of Old Faithful. It forms over one-half of the section of 15 feet of sinter exposed in the crater walls of the Excelsior Geyser. This sinter we know to be the result of the growth and incrustation of little algæ, which form a cedar-colored (*Calothrix gypsophila Kg.*, or olive (*Mastigonema thermale*) slippery coating on the surface of the deposit. The analogy is so perfect that there seems but little doubt that the New Zealand sinter is the result of the growth of similar or allied algæ.

Other specimens of the hot-water deposits of the Rotorua Springs resemble blocks of diatomaceous earth and vary from a loosely com-

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[2] Skey : Trans. N. Z. Inst., vol. 10, p. 433.

pacted mass of pulverulent silica to a dense and almost jaspery sinter. The impalpable particles composing this material are angular and consist almost wholly of milky or transparent glassy silica. Analysis No. III of the following table shows this substance to be a mixture of clay and silica of the same composition as the material incrusting logs immersed in the siliceous waters of the Yellowstone, and often lining the hot-spring bowls.

The following analyses of three types of the Rotorua sinters were made by Mr. J. Edward Whitfield:

*Analyses of Rotorua Sinters.*

| | I.—Geyserite. | II.—Algæ sinter. | III.—Pulverulent silica. |
|---|---|---|---|
| $SiO_2$, silica | 90.28 | 92.47 | 74.63 |
| $Al_2O_3$ ($+Fe_2O_3$) | 3.00 | 2.54 | 15.59 |
| CaO, lime | 0.44 | 0.79 | 1.00 |
| MgO, magnesia | Trace. | 0.15 | Trace. |
| $Na_2O$, soda | | | 0.30 |
| $K_2O$, potash | | | 1.02 |
| Ignition | 6.24 | 3.99 | 7.43 |
| Total | 99.96 | 99.94 | 99.97 |

The remaining specimens from Rotorua consist of a hot spring sandstone, produced by the cementation of particles of rhyolitic glass, feldspar, and quartz by the siliceous waters of the springs. The fragments are uniformly angular, well assorted in layers, and bound together by transparent or milky silica. The latter usually forms a very small part of the bulk of the specimen; in only one case does it sheath the grains in a coating of silica, and form a noticeable part of the deposit. Under the microscope thin sections show no traces of enlargement of the crystal fragments. Though a true hot spring deposit, this material can not claim the name of siliceous sinter. Two of the specimens contain very showy leaf impressions, but the details of veination are not preserved, and the woody tissue is absent. A white "mineral wool" occurring in other specimens of this nature is perfectly silicified woody fibre. Such sandstones are common about the hot springs of the Norris and Shoshone Geyser Basins and other localities of the Yellowstone Park, where they are formed by the cementation of material washed into the springs from the surrounding slopes of disintegrating or decomposed rock.

Besides the sinters from Rotorua, the collection contains a few specimens from the famous White Terrace. This sinter opal closely resembles the deposits of the Coral Spring, whose water, like that of the lost White Terrace, is opalescent with silica, which is carried in pseudo-suspension, and which rapidly coats articles immersed in it. Two jaspery sinters from Whangerei—a seaport about eighty miles

north of Auckland—are very beautifully colored, in red and green bands, but are of no especial interest.

No information is obtainable relative to the comparative abundance of the different types of sinter, but the prevalence of acid and comparative scarcity of alkaline waters shown by the list of springs published by Dr. Hector leads to the belief that algous sinter forms a smaller proportion of the siliceous deposits than it does at most of the geyser basins of the Yellowstone, where the waters are chiefly alkaline. The general character of the springs shows that Rotorua resembles the Norris Basin more closely than any other locality in the Park.

## SUMMARY.

In the light of the knowledge gained in the Yellowstone Geyser Basins, the observations of Prof. W. H. Brewer, referred to in the first part of this paper, acquire a new interest, and it seems quite probable that the gelatinous silica containing algæ which he found at Steamboat Springs, Nevada, may resemble that so abundant in the hot waters of the Park, and that a part, at least, of the siliceous deposits found at Steamboat Springs may have been formed by algous life. The fibrous sinter from the Azores, called Michaelite, occurring about springs where algous vegetation was found to be abundant, certainly suggests a possible like origin. The data accessible are far too meager to hazard any conjectures as to the nature of the Iceland or New Zealand sinters, but the occurrence of algæ in these waters is significant in this connection.

It is believed that the facts recorded in the preceding pages establish—

1. That the plant life of the calcareous Mammoth Hot Springs waters causes the deposition of travertine, and is a very important agent in the formation of such deposits.

2. The vegetation of the hot alkaline waters of the Geyser Basins eliminates silica from the water by its vital growth and produces deposits of siliceous sinter.

3. The thickness and extent of the deposits produced by the plant life of thermal waters establishes the importance of such vegetation as a geological agent.

# ON THE GEOLOGY AND PHYSIOGRAPHY OF A PORTION OF NORTHWESTERN COLORADO AND ADJACENT PARTS OF UTAH AND WYOMING.

BY

CHARLES A. WHITE.

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# ON THE GEOLOGY AND PHYSIOGRAPHY OF A PORTION OF NORTHWESTERN COLORADO AND ADJACENT PARTS OF UTAH AND WYOMING.

By Charles A. White.

## TOPOGRAPHY OF THE DISTRICT.

Among the many phenomena which are of peculiar interest connected with the geology and physiography of the western portion of our national domain none are more worthy of special attention than those occurring in the region which embraces northwestern Colorado and adjacent parts of Utah and Wyoming. Those which are to be specially considered in this article relate directly to geological structure on the one hand, and to surface drainage on the other, as these conditions now exist in that region ; and although the conditions referred to have originated in forces which have acted in intimate relation with one another, they are referable to two different categories of dynamic action that were in part complemental and in part antagonistic; that is, the one category includes those movements of the earth's crust which have resulted in the elevation of plateau and mountain masses, and the other the forces which have effected the disintegration and the immense degradation which the masses so elevated have suffered.

The whole region round about the Uinta Mountains abounds in striking topographical and geological features, the principal of which have been graphically described by Powell ;[1] but I have selected for special discussion a few examples possessing unusual interest which pertain to each category, and which occur within a comparatively small district. This district lies within that great elevated portion of the continent which Powell and Gilbert have called the Plateau Province,[2] and which is one of the grandest fields for geological study that have ever been investigated. But as the plan of this article does not embrace a detailed description of the geology and topography of the district referred to, I shall present only such descriptions and

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[1] See Geology of the Uinta Mountains, by J. W. Powell ; and also Exploration of the Colorado River of the West and its Tributaries.

[2] Geology of the Uinta Mountains, pp. 3–7.

facts as are deemed necessary to the elucidation of the special subjects selected.

No part of this district, except a small area immediately adjacent to Green River at the south side of the Uinta Mountains, is less than 5,000 feet above the level of the sea, and a large part of the uneven surface besides the mountainous portion has still greater elevation. Indeed, the land surface of this district which I shall speak of as low when discussing the mountains is only comparatively so, for much of it has a greater elevation above the sea than have some important mountain ranges.

The foot-hills of the Park Range, which is a western portion of the great Rocky Mountain system, lie along the eastern side of the district. Upon its northern border lies the broad region of open country known as Green River Basin; the eastern end of the Uinta Mountain range occupies the western portion, and White River Valley lies along its southern border.

While some portions of the surface of this district consist of open or comparatively plain country, much of it is hilly besides those portions which may properly be designated as mountainous. Besides the eastern end of the Uinta Mountains, there are several other prominent topographic features within the limits of this district. The Danforth Hills rise upon the space between Yampa and White Rivers in the eastern part of the district. Yampa Plateau and Midland Ridge are conspicuous features of the southwestern part; and other more or less isolated elevations worthy of the name of mountains, occur in different portions of it. Among the latter are Junction and Yampa Mountains, which, because of their peculiar structure rather than because of their great prominence as topographic features, are to receive special consideration. They are two isolated mountains lying eastward from and in line with the Uinta Range. They rise abruptly out of the basin or broad valley through a part of which Yampa River flows, and which, for reasons that will be made obvious, I have called Axial Basin.

The principal drainage of the district is effected by Green River, its tributaries, White and Yampa Rivers, and by Snake River, a tributary of the latter. Green River is itself the principal tributary of the Colorado of the West, or more properly speaking, it is the northern portion of that river and ought never to have received another name.

This district is a part of the great arid region of the continent, and therefore the low-land tributaries of the rivers are mostly dry during the summer, which is the only part of the year during which surveys are practicable, mainly because at other times the excess of water in the rivers renders them unfordable. That is, in summer only the main portions of these rivers, and a few branches supplied by perennial springs, contain water, and this is mostly derived

GEOLOGICAL MAP OF A PORTION OF NORTHWESTERN COLORAD

BY CHARLE

IN PART COMPILED FROM THE PUBLISH

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U. S. GEOLOGICAL SURVEY.


TERTIARY.

BROWNS PARK. B

BRIDGER, GREEN RIVER, WASATCH T

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JURA-TR

J

AND ADJACENT PARTS OF UTAH AND WYOMING TERRITORIES.
A. WHITE.
MAPS OF POWELL, HAYDEN, AND KING.
Miles
20 30
1000 Feet.

NINTH ANNUAL REPORT PLATE LXXXVIII.


A. Hoen & Co. Lith. Baltimore.

S. CARBONIFEROUS. UINTA SANDSTONE. ARCHAEAN. ERUPTIVE ROCKS.

Ca U A E

from mountain tributaries. Consequently, while active erosion of the general surface is suspended there during a large part of the year, direct corrasion of the river beds is constant. Passing mention may be made of the fact that this constancy of corrasion has prevailed in that region through a long period of time, a part of the results of which are the numerous deep and narrow cañons now found there.

In consequence also of the general aridity of the region during a large part of the year vegetation is sparse upon the lower plain and hilly lands, which are always the drier, and even that of the mountains is not usually sufficient in amount to materially hinder the study of the underlying formations by obscuring them. This condition, together with the rapid removal by erosion during the winter months of the debris resulting from the disintegration of the formations greatly facilitates the study of the geology of that region.

Other important features of this district are its cañons. These will necessarily be referred to, and in part described on following pages. Those of Yampa River, although shorter and less deep than many others, will receive special attention because of their peculiar characteristics, and of their extraordinary relation to Junction and Yampa Mountains, and to the Uinta Range. Besides a discussion of certain of the mountains and cañons of this district, evidence will be presented that the Uinta and Rocky Mountain ranges have important structural relations with each other although their axes are at nearly right angles, and although there are considerable differences between their older rock formations respectively.

Partial descriptions of the mountains and cañons referred to have been published by Powell,[1] King,[2] and Hague & Emmons,[3] and by myself,[4] but while omitting many matters of great interest, I shall attempt a somewhat fuller presentation of the special subjects selected than has heretofore been published, and try to point out more clearly the significance of certain phenomena which have been observed there.

## GEOLOGICAL FORMATIONS OF THE DISTRICT.

As the phenomena which it is now proposed to discuss pertain to the elevation, displacements, and degradation of the great formations of stratified rocks that prevail in the region which embraces the district before designated, it is necessary to give some account of them. The following table comprises a list of these formations, beginning with the latest, together with the estimated thickness of each as they have been measured in the region embracing the eastern

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[1] Geology of the Uinta Mountains.
[2] U. S. Geol. Expl. 40th Parallel, vol. 1.
[3] U. S. Geol. Expl. 40th Parallel, vol. 2.
[4] Annual Report U. S. Geol. Surv. Terr., for 1876.

end of the Uinta Range. Following the list, a description of each formation is given, so far as is deemed necessary for the present purpose:

*Table of the Formations.*

| | | | Feet. |
|---|---|---|---|
| Cenozoic | Tertiary | Brown's Park group | 1,200- 1,800 |
| | | Bridger group | 100- 2,000 |
| | | Green River group | 1,400 |
| | | Wasatch group | 2,000- 2,500 |
| Mesozoic | Cretaceous | Laramie group[1] | 2,000- 3,000 |
| | | Fox Hills group | 1,800 |
| | | Colorado group | 2,000 |
| | | Dakota group | 500 |
| | Jura-Trias | | 2,500- 5,000 |
| Paleozoic | Carboniferous | | 3,000- 4,000 |
| | Uinta sandstone | | 12,000-14,000 |
| Archean | | | |

ARCHEAN ROCKS.

The Uinta Mountain range is unlike the Rocky Mountain ranges in not having the crystalline Archean rocks exposed as a central or axial mass. It is highly probable that Archean rocks rose in the axis of the Uinta fold during its elevation, somewhat as they are represented in the generalized section, Fig. 58, and as they rose in the orogenic folds of the Rocky Mountain system where they are very conspicuous. So far as is known, however, they were not sufficiently elevated in the axis of the Uinta fold to have become bared by the erosion which has given the Uinta Mountains their present form. The only rocks of this age which are exposed to view in the district under discussion, or that are known to be exposed in any part of the fold, are not in its axis; they occupy a small area upon its northern flank, not far from the eastern end of the main fold. The fact that the Uinta quartzite rests unconformably upon these Archean rocks suggests the probability, first mentioned by Powell,[2] that the latter were raised by a circumscribed uplift in Archean time; and that they constituted an island which remained such while at least the earlier part of the Uinta strata were being deposited. In the subsequent elevation of the great fold it is only a part of this island portion of the great Archean mass that has been brought to view.

While these rocks are probably geologically equivalent with the Archean rocks of the Rocky Mountain ranges, it is worthy of remark that those of the Uinta Mountains present considerable lithological differences from those of the Rocky Mountain system. That is,

[1] See remarks with foot-note reference on pp. 690, 695, 696.

[2] See Geology of the Uinta Mountains, p. 139.

although they both contain similar component minerals, their proportions in the rocks of the two ranges are very different. A white or light gray quartz is so largely prevalent in the Uinta Mountain Archean, and the other minerals are in such small proportion, that Powell designated it as a quartzite in the name which he gave to the formation.[1]

These rocks not having been observed in the axis of the Uinta fold, it will not be necessary to take them any further into consideration now, nor when estimating the amount of vertical displacement of the strata entering into that fold, except to regard them as constituting the floor of the Uinta quartzite.

## UINTA SANDSTONE.

This great formation extends from end to end of the Uinta range of mountains and constitutes a large part of their bulk. It is also found in the isolated upthrust mountains just beyond the eastern end of the range which have already been mentioned; but it has not been recognized as such in any part of the Rocky Mountain system, nor elsewhere northward, southward, or eastward from the Uinta Range. This is somewhat remarkable in view of the uniform character of the formation, and of its great thickness in that range which, according to Powell, reaches a maximum of 14,000 feet.

This formation has usually a brown, or dark ferruginous color, and the ordinary regularly bedded character of sandstone. In some places it has nearly the compactness of true quartzite, but usually its hardness is that of ordinary firm sandstone. In some places soft and shaly layers are found, but these are exceptional. As a whole, the general lithological character of the formation is readily recognizable; and it has considerable uniformity throughout its geographical extent, and from the lowest to the uppermost known strata.

Much difference of opinion has prevailed as to the true geological age of the Uinta Sandstone. King, who gave it the name of Weber Quartzite, states that it is of Carboniferous age;[2] in which view Hague and Emmons concur.[3] Powell referred it provisionally to the Devonian;[4] Marsh was disposed to regard it as belonging to the Silurian,[5] at least in part; and Hayden was of the opinion that it ought to be referred to the Lower Silurian.[6]

[1] See Geology of the Uinta Mountains, p. 137.

[2] U. S. Geol. Expl. 40th Parallel, vol. 1, pp. 152 and 240.

[3] U. S. Geol. Expl. 4th Parallel, vol. 2, pp. 290, 323, and 452. In a foot-note to page 99, however, they indicate some doubt as to the correctness of their opinion as first formed.

[4] Geology of the Uinta Mountains, p. 141. But it is proper to state that I have personal knowledge of the fact that for the past ten years Major Powell has regarded this formation as of pre-Cambrian age.

[5] Am. Jour. Sci., 3d series, vol. 1, p. 193.

[6] Ann. Rep. U. S. Geol. Surv. Terr., for 1870, p. 50.

Whatever may be the geological age of the Uinta Sandstone, it is certain that the undoubted Carboniferous rocks of this district rest directly upon it; and, according to Powell, there is in many places distinct unconformity between them. It is also true that within this district no other rocks than the Archean have been found beneath the Uinta Sandstone.

## CARBONIFEROUS.

The conditions attending the deposition of the Carboniferous series in that far western region were different from those which attended the deposition of the rocks of the same age in the region drained by the Mississippi; and the full series in the two regions respectively are therefore differently divided. In the region of the Uinta Mountains the Carboniferous series has been divided into three nominal formations, mainly upon lithological grounds, all of which are strictly conformable with one another. The series in this region consists in large part of limestones, but in part of sandstones, all of which usually are regularly bedded, and most of which are compact and hard. Shaly or softer strata rarely occur among them, and coal, which so distinctly characterizes the series elsewhere, has never been discovered among its strata there. Because of this strict conformity of the three nominal formations of the Carboniferous series with one another in this region, and the generally firm character of all the strata composing them, the whole series will be treated as a single unit in the following discussions.

Attention should here be called to the fact that the Paleozoic strata, that is, those of the Uinta and Carboniferous formations, consist as a whole of much harder rocks than those of the later formations, descriptions of which now follow.

## JURA-TRIAS.

Resting comformably upon the Carboniferous in this district there is a series of sandstones which have usually been regarded as of Triassic age, but it is probable that the lower portion ought to be assigned to the Carboniferous series. These sandstones consist of yellowish, moderately firm strata above, of yellowish softer strata below; and between them a thick mass of bright red or brownish-red strata, most of which are moderately firm. The Triassic age of all of them except the lower portion just mentioned, has rarely been questioned; but the strata of that portion being usually barren of fossils, its geological age has not been determined with as much accuracy as could be desired.

Upon the Triassic sandstones comes a small series of beds which are usually referred definitely to the Jurassic. They consist of soft,

variegated bad-land[1] sandstones, with occsionally harder layers; and near the base of this comparatively thin series of strata, a few feet in thickness of sandy, shaly, or often calcareous, fossiliferous layers, are usually found. This Jurassic portion of the Jura-Trias series is hardly more than one-fifth of the whole in thickness, but its distinguishing characteristics are quite uniform over a wide geographical area.

## CRETACEOUS.

The full Cretaceous series in this district, exclusive of the Laramie, reaches a thickness of 4,300 feet; and the Laramie has here a thickness of 2,000 to 3,000 feet additional. In accordance with the views expressed by me on a former occasion[2] I here place the Laramie among the Cretaceous formations. This arrangement is the more desirable in the present case because the stratigraphical and not the paleontological relations of the formations are discussed. That is, in these discussions prominence is necessarily given to the fact that not only does the Laramie group rest comformably upon the marine Cretaceous, but the former group is fully involved with all the formations earlier than itself in all the displacements which are mentioned as having occurred in this district, while the later formations were not thus fully involved.

*The Dakota Group*, the lowermost of the Cretaceous series in this region, and the equivalent of No. 1 of the Upper Missouri section of Meek & Hayden, here presents nearly the same general characteristics which it possesses throughout the great Rocky Mountain region. The upper portion consists of yellowish or brown rough sandstone, the middle portion of variegated sandstone, and the lower portion of irregularly bedded pebble conglomerate. The strata are generally firm, and their escarpments prominent.

*The Colorado Group*, the equivalent of Nos. 2 and 3 of Meek & Hayden, consists in this district of dark colored argillaceous shales, and clayey and sandy strata, with occasional layers of moderately firm sandstones. All these strata are so soft that they seldom appear in escarpments; and because of the facility with which they are eroded they have given place to certain of the basins and broader valleys.

*The Fox Hills Group*, the equivalent[3] of Nos. 4 and 5 of Meek &

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[1] The Mauvaises Terres or Bad-Lands of the West are usually covered with débris which is often so soft as to yield to the pressure of the foot; but the material before erosion is almost always a soft earthy sandstone, designated as bad-land sandstone.

[2] See White, C. A., on the relation of the Laramie Group to earlier and later formations: Am. Jour. Science, 3d series, Vol. 35, pp. 432–438.

[3] Since this article was written I have adopted the name Montana Group proposed by Mr. Geo. H. Eldridge for the equivalent of Nos. 4 and 5 of the Upper Missouri section. See Am. Jour. Sci., Vol. XXXVIII, Oct. 1889, pp 313–321.

Hayden, here presents some differences in lithological character from that which it possesses in other districts. The upper part consists mainly of the more common, somewhat soft sandstones, but the lower portion is so largely made up of soft, sandy, and argillaceous shales, similar to the shales of the Colorado Group, that in the absence of characteristic fossils it is difficult to distinguish the two formations apart where they are found in contact.

*The Laramie Group* consists mainly of sandstones and sandy shales. The sandstones, while not often very hard, are frequently so firm that they form abrupt escarpments; and they also form prominent hogbacks when tilted at a high angle. The absence of true marine fossils in this great formation, and the presence throughout its wide geographical extent of such forms as now characterize fresh and brackish waters is worthy of notice. These facts indicate that the formation was deposited in a great inland sea, or one which was largely cut off from the open ocean by land barriers which were elevated at the close of the Fox Hills epoch. These barriers probably did not reach any considerable height above the sea; or at least their elevation was evidently not a part of the orogenic movements which began at the close of the Laramie period, and resulted in the production of the Uinta, and other great folds upon a broad and rising continental area.

## TERTIARY.

The Tertiary strata of this district are all of fresh-water origin, and are divided into four groups. The three lower ones are usually referred to the Eocene without hesitation; while the upper one is sometimes referred to the Eocene, sometimes to the Miocene, and sometimes to the Pliocene. The three lower groups are strictly conformable with one another, and the lowest one appears in this district to rest conformably upon the Lamarie, where the contact has been observed. The upper or Brown's Park group, however, is conspicuously unconformable with the other Tertiary formations, as well as with all the other formations with which it is found in contact.

*The Wasatch Group*, the equivalent of the Bitter Creek group of Powell and of the Vermillion Creek group of King, consists in this district of alternating harder and softer sandstones below, and of bad-land sandstones above.

*The Green River Group* consists of coarse, irregularly bedded sandstone above, and sandy and calcareous, with occasionally carbonaceous, layers below, which are generally thin bedded, and occasionally shaly. The maximum thickness of both divisions in this district is only about 1,400 feet, which is about equal to the full thickness that this formation is known to have elsewhere.

*The Bridger Group* reaches a thickness of only about 100 feet in this district, but northwestward from this district it has been

observed to reach a maximum thickness of about 2,000 feet. It consists mainly of bad-land sandstones, but sometimes the layers have considerable firmness.

*The Brown's Park Group* is regarded as equivalent to the Uinta group of King.[1] The latter name was given by King to those strata of the group that occur on the south side of the eastern end of the Uinta range; but he did not recognize those upon the north and east sides as being different from the Green River group.[2] The southern portion presents a reddish or yellowish ferruginous aspect; while the northern and eastern portions have throughout an unusually light color. This difference in color is perhaps due to the derivation of material from the red Triassic sandstones in the one case, and from the light-colored Bridger and Green River groups in the other.

The Brown's Park group consists mainly of sandy material, usually fine grained, with occasionally gravelly strata. The strata are sometimes evenly bedded and firm, but they are often irregular and friable; and they are frequently incoherent where exposed at the surface. Because it rests unconformably upon all the other formations with which it comes in contact, it obscures the underlying geological structure in numerous places; but seldom to such an extent as to leave the real character of the structure in doubt.

Besides the formations described in the foregoing paragraphs there are certain later surface accumulations; but as they have no necessary relation to the special subjects of this article they are not represented upon the accompanying map; and they are mentioned here only by name. They are the Bishop's Mountain Conglomerate (= Wyoming Conglomerate of King), the local drift derived, apparently by glaciation, from both the Uinta and Park ranges, and the Quaternary deposits of the river valleys. Eruptive rocks are also found in the eastern part of the district, as represented upon the accompanying map; but a description of them is not deemed necessary for the present purpose.

## DISPLACEMENTS.

The displacements which these formations have suffered in this district are numerous, and some of them are of great vertical extent. They are mainly in the form of folds or of more circumscribed uplifts, and of more or less conspicuous tiltings. The principal displacement within, or that reaches within, this district is the great Uinta fold.

[1] Not the Uinta group, or Uinta quartzite of Powell (op. cit.).

[2] See Atlas U. S. Geol. Expl. 40th parallel, Map II, east half. Also compare with the map accompanying this article, and with map B, of atlas of Geology of the Uinta Mountains.

THE UINTA FOLD.

This fold has usually been described as having its eastern end terminating abruptly in northwestern Colorado. As a conspicuous fold it does so terminate; but continuous with its axis to the eastward there is a long gentle anticline which reaches by a broad curve to the foot-hills of the Park Range, and which I regard as a continuation of the Uinta fold. I therefore divide the Uinta fold into two portions, namely, the main portion or the Uinta fold proper, and the inceptive portion of the same. For convenience of description I shall so designate them in this article.

Both Powell[1] and King[2] have shown that the Uinta fold is composed of a series of formations of stratified rocks of great thickness, which have all been elevated together along an approximately east and west axis. The fold proper is about one hundred and fifty miles in length, and from thirty to forty miles in width at the extreme limit of the upturned strata at either side. Its western end is blended with the Wasatch Range in Utah, which it meets at nearly right angles. Its eastern terminus is about thirty miles within and east of the western boundary of Colorado, and about the same distance from the northern boundary. Its axis is not quite straight, the maps of its surveys showing gentle and somewhat irregular meanderings. One of these gives its eastern end a gentle curve a little to the south of its general course, which brings it into line with the curved axis of the inceptive portion of the fold.

This great fold is remarkable for its simplicity and its peculiar characteristics, as compared with the other orogenic displacements which have occurred in that great region; that is, while its western end blends with the Wasatch Range, and its eastern end has structural relation with the Rocky Mountain system, the great fold, as a whole, has certain characteristics peculiarly its own, and it has also few lateral complications. It is true there are certain minor plications adjacent to the range; but, with the exception of the Yampa Plateau[3] fold, these are comparatively small and inconspicuous.

It is out of the formations which were brought up in the great Uinta fold that the mountain range, as we now know it, has been carved. This carving has been accomplished by the ordinary process of erosion which is, and always has been, in constant action upon the surface of the earth; but it has here been effected upon a scale of such magnitude that the present majestic peaks may be properly regarded as only shreds of the enormous mass which has been uplifted there. Some of the higher peaks of the range have now a

[1] Geology of the Uinta Mountains.

[2] U. S. Geol. Expl. 40th Parallel, vol. 1.

[3] Yampa Plateau must not be confounded with Yampa Mountain. Separate names for each would be used here if it were deemed expedient to change either of them after their long publication and use.

height of more than 7,000 feet above the general surface of the surrounding region; and the elevation of the region itself is so great that the summits of those higher peaks are more than 13,000 feet above the level of the sea.

Powell has shown that the Uinta fold is of a peculiar type,[1] being characterized by an abrupt upward flexure of the strata at either side, which in some places is a true fault, while between the two abrupt side flexures the fold is broad, and its convexity comparatively gentle.

FIG. 57. Diagram representing the Uinta type of displacement.

The accompanying diagram (Fig. 57) copied from Powell, illustrates this peculiar form which he designated as the Uinta type of displacement. This peculiar type characterizes not only the main fold, but it is recognizable in some of its subordinate uplifts; for example, in the midland and Yampa Plateau folds.

Before proceeding with a description of the great fold it is proper to refer to some other matters which are of general importance in this connection. Attention has been called to the fact that the Carboniferous and Uinta Sandstone formations are mainly composed of hard rocks. The later formations, from the Jura-Trias to the Laramie inclusive, although their strata are often firm, are, as a whole, composed of softer rocks, many of them yielding readily to disintegrating action. The same may be said of the three lower Tertiary formations, while the upper one, or Brown's Park group, is in still larger part composed of friable materials. It should be further mentioned that all these softer formations are mainly composed of siliceous sand.

These facts are mentioned here because of their bearing upon the question of the origin of the present remarkable topographic features of this region. One may readily understand that if the earlier formations had consisted of softer rocks than the later ones, the topographic features resulting from their displacements and from the erosion which the whole have suffered, would have been very different from what they now are. Again, one quickly reaches the conclusion that it is the siliceous materials of the softer formations that have been made the instrument of corrasion of the harder rocks, which fact will presently be discussed.

Other conditions being equal the rapidity and extent of disintegration and erosion would depend largely upon the varying hardness of the rocks thus effected, but it is not always the case that the softer

[1] Geology of the Uinta Mountains, p. 17.

rocks have suffered most in this respect. In fact, the hardest rocks have yielded to such action, and to the more direct action of corrasion, to a surprising extent, and in this district numerous examples

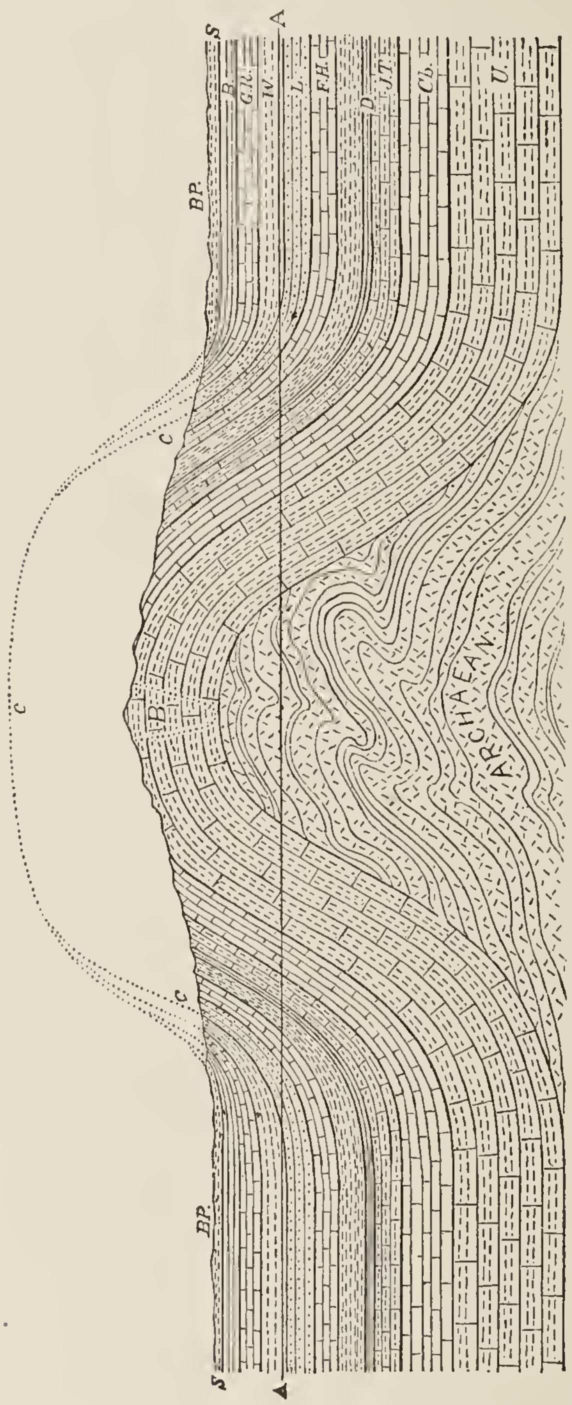


Fig. 58. A generalized transverse section of the Uinta fold.

The irregular line, S. S., represents the land surface, and the straight line, A. A., the sea level. The dotted line at either side of B. represents the depth to which Green River has cut its cañon in traversing the Uinta Range. The dotted lines above the surface line represent those portions of the formations which have been eroded, and the extent to which they would have been elevated in the fold if they had suffered no erosion.

The dotted line, c. c. c., is continuous with the top of the Laramie group. This indicates that all the formations beneath that line were fully involved in the fold; while the other dotted lines, which lap upon either side, represent the eroded portions of the four fresh water Tertiary formations which were successively less and less involved in the fold as the elevation progressed.

The initial U. indicates the Uinta Sandstone; C. B. indicates the Carboniferous; J. T., the Jura-Trias; D., the Dakota group; Co., the Colorado group; F. H., the Fox Hills group; L., the Laramie group; W., the Wasatch group G; R., the Green River group; B., the Bridger group, and B. P., the Brown's Park group.

are found which seem to show that they have offered as little resistance to erosion as the softer rocks have done, and in some cases, at least, they seem to have offered less resistance to the corrasive action of rivers than have the softer rocks. The reason for making this latter suggestion will be made apparent in the following paragraphs which refer to river cañons.

It is the softer rocks which have yielded the instrumental material for the corrasion of the cañons in the harder formations. If there

had been no thick formations of hard strata there could have been no narrow, deep cañons, and if there had been no extensive formations of friable siliceous rocks in the same or adjacent district the cañons could not have been cut for the want of the proper instrument. In short, and as has already been mentioned, it is sand, together with other rock fragments, that has served as the instrument of corrasion, while the moving water of the rivers has served as the vehicle for transporting the instrument, and as the medium for applying the power by which the corrasion was accomplished.

Let us now return to a consideration of the great Uinta fold. The study of the present geological structure of a region enables us to reach important conclusions as to the past geological history of that portion of the earth of which it forms a part. Such a study of the region round about the Uinta Mountains shows that the formations there were not all equally involved in the great fold. The present condition of those formations and their relation to one another, show that all of them, from the Uinta sandstone to the Laramie inclusive, were equally involved in that fold, while the relation of the Tertiary formations to those older ones, show that these were only partially involved in it. These relations of the formations to one another, and to the great fold, are graphically illustrated by the accompanying generalized section of the Uinta fold. (Fig. 58.)

From the foregoing, and other correlated facts, the inference is drawn that the elevation of the great Uinta fold was begun immediately upon the close of the Laramie period, and before the first of the fresh-water Tertiary strata were deposited; and that it was nearly complete before the deposition of the Brown's Park group; the latest of the fresh-water Tertiary series. Other facts already referred to, indicate that the waters in which the Laramie group was deposited rested at a level which was little, if any, above that of the open sea; and the character and present condition of the Tertiary formations show that they were successively deposited at respectively different heights above that level. That is, they were deposited in great lakes, the existence, extent and elevation of which were respectively determined by the varying configuration of the general land surface as elevation and degradation progressed.

The facts which have been presented show that the orogenic movements[1] which have resulted in the production of the Uinta and other mountain-making folds were approximately synchronous in their origin, and coeval as to time-limits of their duration, with the epirogenic movements by which the great continental area upon which those folds rest reached its present elevation.[1] These con-

[1] Certain epirogenic movements must necessarily have taken place to form the barriers by which the Laramie sea was cut off from the open oceans. Local unconformity among the Laramie strata, which has been observed near the top of the group in southern Wyoming, indicates that certain other premonitory movements took place before the Uinta fold was well defined.

clusions, and the facts upon which they are based, are of importance in estimating the amount of vertical displacement which has taken place in the Uinta fold, because they constitute the data by which we determine the upper and lower limits of the series of formations which were wholly involved in it, and which alone need to be considered in that immediate connection.

In the case of many mountain ranges it is difficult to estimate the amount of vertical displacement which has taken place in their elevation. But the Uinta Range and its foot-hills being composed almost entirely of a series of at least approximately comformable formations of stratified rocks, the thickness of each of which has been ascertained, an estimate of the amount of vertical displacement there may be made with a good degree of confidence in its general accuracy.

The formations later than the Laramie not having been involved in the beginning of the uplift, and the Archean rocks not being exposed in the heart of the Uinta Range, both are excluded from the estimate here given. This estimate is based upon the ascertained thickness of each of the formations from the Uinta sandstone to the Laramie, inclusive, the elevation above the sea of the lowermost observed strata of the Uinta sandstone, and upon the fact, as assumed, that the top of the Laramie was little, if any, above the level of the sea when the upward movement of the fold began.

In making this estimate I have thought best to use the minimum thickness of each formation as given in the foregoing table, lest I should appear disposed to exaggerate a statement of facts which are obviously so remarkable. The aggregate thickness of the formations from the Uinta sandstone to the Laramie, inclusive, is thus found to be 23,800 feet. Add to this 5,000 feet as the height above the sea at which the lowermost strata of the Uinta sandstone have been observed, and, we have an aggregate of 28,800 feet, or about five and a half miles.[1]

It is of course not to be understood that even the uppermost of the strata of the uplifted series ever reached a height above the level of the sea at all approximating the full amount of vertical displacement. In fact, we have no reason to suppose that any portion of the Uinta Range ever attained a much greater height than the higher peaks now have, because erosion of even the hardest rocks closely balances elevation after certain heights are reached.

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[1] Accepting Powell's statement as to the marked unconformity between the base of the Carboniferous and the top of the Uinta sandstone, and his views as to the pre-Cambrian age of the latter, geologists will readily perceive their great significance. But these facts and conclusions do not necessarily affect the estimate here given of the amount of vertical displacement in the Uinta fold. They point to a great blank in geological history as regards the region here discussed, the closing epoch of which was long anterior to any of the movements and displacements described and referred to in this article.

The readier yielding of the softer than of the harder rocks to disintegrating and erosive action under like conditions has already been referred to. This fact has seeming exemplification in the presence of the older and harder rocks in the higher mountains in this district, and the removal of the later and softer ones from the more elevated portions of the uplifts, which must necessarily have once rested there. But it must be borne in mind that it would have been impossible for even the harder strata to resist the constantly active forces of degradation, at the great heights to which the softer ones would have been carried, if they had not been removed by erosion while they were being elevated. With these explanations we will now consider certain other topographic and structural features of this district which it is the object of this article to discuss.

The eastern terminus of the Uinta fold proper is by a dip of its greatly elevated strata, which is quite as abrupt as it is at the sides of the fold. This terminal dip has a broadly sweeping semi-elliptic trend, which is marked by the upturned edges of the later formations that were involved in the fold, as they also mark the trend of the dip at either side. These later formations having suffered complete erosion from a broad space on either side of the axis of the fold, the present mountains are found to be composed of the earlier formations almost alone, while the characteristic lateral dips are mainly observable in the later ones.

The semi-elliptic form of the trend of the upturned strata is due to the preservation of the type of uplift of the fold, even to its very end. The upturned strata which mark that trend, however, are to a considerable extent obscured from view upon the northern side. This is in part due to a remarkable down throw of the strata which were there involved in the fold, as has been shown by Powell,[1] and in part to the presence there of the later Tertiary formation which bears the name of the park, as already described.

The termination of the great fold by a sudden dip while preserving nearly its full width is worthy of remark, because it shows that the main portion of the fold does not pass gradually into the inceptive portion. This condition might perhaps be regarded as an indication that the latter portion is not really a continuation of the former if it were not true that similar conditions are observable in the case of other displacements which are immediately connected with both the great fold and its inceptive portion. But this subject will be further considered in following paragraphs.

## THE YAMPA PLATEAU, AND OTHER SUBORDINATE FOLDS.

Before proceeding eastward, along the inceptive portion of the Uinta fold, however, let us briefly consider three subordinate up-

[1]Geol. Uinta Mountains, pp. 208, 209.

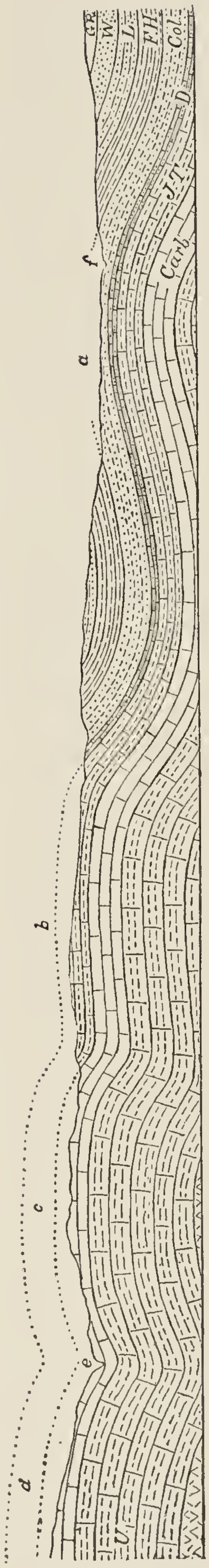

FIG. 59. Section across Raven Park, Midland Ridge, Yampa Plateau, and a portion of the main Uinta Range.

*a*, Raven Park uplift; *b*, Midland fold; *c*, Yampa Plateau fold; *d*, a portion of the main Uinta fold; *e*, Yampa River; *f*, White River; U, Uinta sandstone; Carb., Carboniferous; JT, Jura-Trias; D, Dakota group; Col., Colorado group; FH, Fox Hills group; L, Laramie group; W, Wasatch group; GR, Green River group.

lifts which lie adjacent to the southern side of the eastern end of the main fold and another, the Danforth Hills uplift, which lies adjacent to the south side of the inceptive portion of that fold. Two of the first mentioned uplifts are in the form of somewhat short folds which lie closely adjacent to each other, as well as to the main fold, with the axis of which the axes of these two subordinate folds are approximately parallel. They are designated as the Yampa Plateau and the Midland folds, respectively. The third one, which I have called Raven Park uplift, lies toward the south near to, but not adjoining, the others. It is approximately oval in outline, has a less vertical displacement than the others, and the direction of its longer diameter is nearly northwest and southeast.

It will be observed that these subordinate folds are clustered together at the south side of the eastern terminus of the main portion of the great fold; that the two larger ones terminate suddenly, especially at the eastern end, as does the great fold; and that beyond these abruptly terminating ends there are no indications of a continuation of their axes.

The lateral relation of these subordinate folds to one another and to the main fold is shown in the accompanying section, Fig. 59, the line of which is across them, and approximately upon the meridian of 108° 50′.[1]

The topographic feature known as Yampa Plateau is so closely blended with the mountains of the Uinta Range that it may properly be regarded as a part of the same. It includes the western portion of the Mid-

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[1] The section F. F., which is given at the bottom of the map facing page 60 of Ann. Rep. U. S. Geol. Surv. Terr., for 1876, was intended to represent the same strata and their displacements which are represented in this figure. That section, however, is incorrect, and was published without an opportunity having been given the author of the report to correct it.

land, as well as that of the plateau fold, but it does not extend to the eastern portion of either of them. My present object, however, is to refer to the folds as a part of the series of displacements which it is the special object of this article to consider, rather than to describe topographic features.

Yampa Plateau fold is about 40 miles long from its eastern to its western terminus. Its vertical displacement has been so great as to bring up the Carboniferous rocks, which, by erosion of the later formations, are exposed at the surface along its whole length, leaving those later formations upturned at the ends of the fold. The eastern end terminates as suddenly as that of the main fold by a similar broadly sweeping dip of its strata, and at a point only a little further westward than the terminus of the main fold. Its western termination is by two prominent spurs, called respectively Split Mountain and Section Ridge. Unlike most spurs which are projected from mountain ranges, these are quite regular in structure. Each is closely like the other in this respect, as well as in their dimensions and in the extent of the vertical displacement which their strata have suffered. The central portion of each is composed of Carboniferous rocks, which are continuous with those of the main mass of the plateau, while the Mesozoic rocks are upturned all round their base as they are around the other uplifts in this district.

The axis of the Split Mountain spur extends nearly 15 miles almost due west from the body of the plateau; but the later formations involved having been greatly eroded, the spur as it now exists is much shorter. There is a narrow synclinal valley between it and the main fold; and a shorter more open one between its southern side and Section Ridge, both of which communicate with the open country which stretches away to the southward. The Section Ridge spur is somewhat shorter than the other, although the axial length of this as well as of the other is greater than the breadth, and the direction of its axis is a little to the south of west. The strata involved in these spurs dip regularly around the base of each, and thence trend away at the base of the plateau on the one hand, and that of the Uinta Range on the other. The regularly curved dip around the distal end of each spur is so marked a geological feature that I have applied to it the term partiversal[1] dip.

The vertical displacement of Midland fold is less than that of Yampa fold, so that the Triassic rocks occupy the greater part of its surface, the Carboniferous strata not having been brought to view. Its eastern terminus is by a broad sweeping dip, like that at the east-

[1]A quaquaversal dip, as the term is usually applied, is in all directions from a given point. A partiversal dip is around the vanishing end of an anticlinal axis. The region round about the Uinta Mountain Range contains numerous examples of partiversal dip.

ern end of Yampa Plateau fold, and it retreats a little to the westward, as the last named fold does with relation to the terminus of the main fold.

The Danforth Hills, which have already been mentioned as occupying a portion of the eastern part of this district, rest upon the comparatively gentle fold or uplift to which I have given the same name. This fold lies adjacent to the southern side of the inceptive portion of the Uinta fold and within the broad curve which it makes in its extension from the Uinta to the Park Range. Its lateral position with relation to the inceptive fold is indicated by the section, Fig. 60.

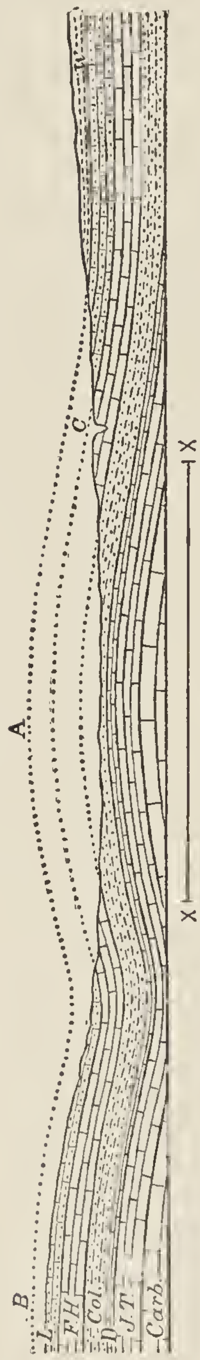


Fig. 60. Section across Axial Basin, 5 miles east of Yampa Mountain, showing the inceptive portion of the Uinta fold, and a part of the Danforth Hills uplift.

A, axis of the inceptive fold; B, north base of Danforth Hills, showing a portion of that uplift; C, Yampa River; Carb., Carboniferous strata; JT, Jura-Trias; D, Dakota group; Col., Colorado group; FH, Fox Hills group; L, Laramie group; W, Wasatch group. The line xx indicates proportionally the longer diameter of the Yampa Mountain upthrust, and approximately, its position with reference to the inceptive axis.

Horizontal scale, 4 miles to the inch; vert'cal scale, $\frac{1}{12}$ inch to 1,000 feet.

These subordinate folds have been briefly described here that they may be referred to in connection with the discussions yet to be made. Let us now return to the eastern terminus of the main portion of the Uinta fold and proceed eastward along its inceptive portion. The axis of this portion of the fold passes along the broad valley which I have called Axial Basin, and thence by a broad curve to the northeastern base of the White River plateau which is a spur of the Park Range. It is not a conspicuous geological feature, but the reality of its existence is plainly apparent on investigation. Its vertical displacement, although considerable, is comparatively slight; and the strata involved are, in Axial Basin, partly covered from view by those of the Brown's Park group. It also becomes somewhat indistinct at its eastern end in consequence of the confusion of dips upon approaching the foot hills of the Park Range, and of the presence there of basaltic outflows. Its general character is shown by Fig. 60, representing a section across it about five miles eastward from Yampa Mountain.

Upon this inceptive portion of the Uinta fold there have been imposed two extraordinary geological features, namely, the Junc-

tion and Yampa Mountain upthrusts,[1] which I regard as the result of localization, or a locally intensified application of the force by which the fold was elevated, and which will now be considered.

## JUNCTION MOUNTAIN UPTHRUST.

Going only two or three miles eastward from the eastern terminus of the main fold, where we have seen the later formations dip so suddenly from view, we come to the western border of Junction Mountain upthrust. Here we find the same strata rise again, even more suddenly than they disappeared ; and we also find that the formations of Paleozoic age, which constitute the high mountain peaks of the Uinta Range only a few miles away, are here again uplifted, not only to the surface of the low land around the mountain, but to a maximum height of nearly 2,000 feet above it. The strata involved in this uplift (which, because of its sharply defined limits, and of the extent of vertical displacement of those strata, I have called an upthrust), occupy an elongate oval area the extreme longer diameter of which is nearly 12 miles, and the shorter about 4 miles. The direction of the longer diameter, being approximately northwest and southeast, is obliquely transverse to the general trend of the axis of the main fold. In this respect, as well as by the peculiar character of displacement of the strata involved, the isolation of this upthrust is quite complete, although it lies so near the terminus of the main portion of the Uinta fold and upon the axis of its inceptive portion.

So sharply have the strata been uplifted in this displacement that they are either faulted or are nearly or quite vertical at a portion of each side of the upthrust; and they also dip very abruptly at other portions, and around its ends. The Mesozoic formations through which the older ones were forced lie around the mountain, but immediately adjacent to it they are largely covered from view by the strata of the Brown's Park group, which lie unconformably upon them. The disturbance which those Mesozoic formations have suffered in that neighborhood beyond the base of the mountain is so slight that one can not recognize it as having been connected with the upthrust movement. That is, their position as marking the presence of the inceptive fold and certain subordinate uplifts does not seem to have been changed by the localized upthrust movement.

[1] In using the terms "uplift" and "upthrust," I do not ordinarily intend to express an opinion as to the actual direction of the movements by which the strata were displaced ; but in describing displacements it seems to be more natural to assume that the lower mass, which is the larger, was the fixed one ; and that the higher, which is relatively the smaller, was uplifted. The former term needs no explanation in such a connection. The latter term is peculiarly applicable to the character of the displacements by which Junction and Yampa Mountains are characterized, as will appear in connection with their description.

The Mesozoic formations which must necessarily have risen upon the top of the older ones within the upthrust area have been removed by erosion as has also a large part of the full thickness of the carboniferous strata which came up beneath them. Therefore, only strata of Paleozoic age now enter into the structure of the mountain proper, while the upturned edges of the later ones, where they have not been sharply severed by faulting, lie around its base.

### YAMPA MOUNTAIN UPTHRUST.

Going from Junction Mountain about 16 miles, along the axis of the inceptive fold, we pass all the way over the low lands of Axial Basin, the surface of which is there mostly occupied by the Brown's Park group, and reach Yampa Mountain, which rises directly upon that axis, as does Junction Mountain. Here we find that the description which has just been given of the Junction Mountain upthrust will apply in all essential respects to this. All around the base of Yampa Mountain the strata of the Brown's Park group cover the immediate borders of this upthrust, even to a greater extent than they do those of Junction Mountain upthrust; but it is readily seen that the two mountains are essentially identical in structure and character, and that they have been produced in a similar manner. Yampa upthrust, however, is smaller than the other, and it is also much farther away from any other much-displaced strata. Its outline is oval, the longer diameter, including all the strata involved, not much exceeding seven miles in length, and its shorter diameter is less than four miles. The longer diameter is nearly at right angles with that of Junction Mountain upthrust, and it is nearly transverse with the inceptive portion of the Uinta axis, upon which it rises. The relation of these two upthrusts to each other, and to the main and inceptive portions of the Uinta fold, is indicated by the section, Fig. 61.

The amount of vertical displacement is about the same in each of these upthrusts, the extent of which is estimated from the thickness of the formations as given in the foregoing table, and from the contour lines on the published topographic maps of that region. The contour line which cuts the top of the Uinta Quartzite in both these mountains passes along the southern side of Axial Basin approximately at the base of the Laramie and top of the Fox Hills group. Referring to the preceding table we find the thickness of the intervening formations to be 11,800 feet. It is plain, therefore, that the amount of vertical displacement in both these mountains is not less than is represented by those figures.[1] That is, within the narrow

[1] The estimate of 8,000 feet given in my report on that region (loc. cit.) was inadvertantly made too small, as may be seen by the data there used, as well as by the figures in the preceding table.

and sharply defined limits that have been described, the strata of which both these mountains are composed have been thrust up a vertical distance of more than two miles; which, in the case of the Yampa upthrust, is nearly equal to one-third the longer diameter of the area affected by it.

As indicating that the amount of vertical displacement in these upthrusts is really greater than has been mentioned, it may be stated that the Fox Hills and Laramie strata referred to have themselves been elevated to a considerable extent in the adjacent Danforth Hills uplift, as shown by the section, Fig. 60. This figure will also serve to illustrate the relation of the Yampa upthrust to the inceptive fold, and to the adjacent Danforth Hills uplift. That is, if within the space indicated by the length of the line *x*, *x*, the strata should be elevated until the base of the carboniferous series reaches the place of the uppermost dotted line, the vertical extent and lateral restriction of the Yampa upthrust will be indicated.

### RELATION OF THE UINTA FOLD TO OTHER FOLDS AND TO THE PARK RANGE UPLIFT.

It is true that the vertical displacement in the case of the two upthrusts is much less in amount than is that of the great fold; but the amount of displacement is far more remarkable in the case of the upthrusts than it is in the case of the fold, because of the very narrow limits within which the displacements in the former case have taken place. The narrow and sharply defined limits of these upthrusts, and the severing of the displaced portions of the formations from the great mass of each respectively, with little or no general disturbance of the latter beyond those limits, may be compared to the action of a large punch on being forced by great power through a number of thick iron plates. The comparison will be more complete if we conceive that the cutting border of such a punch had become

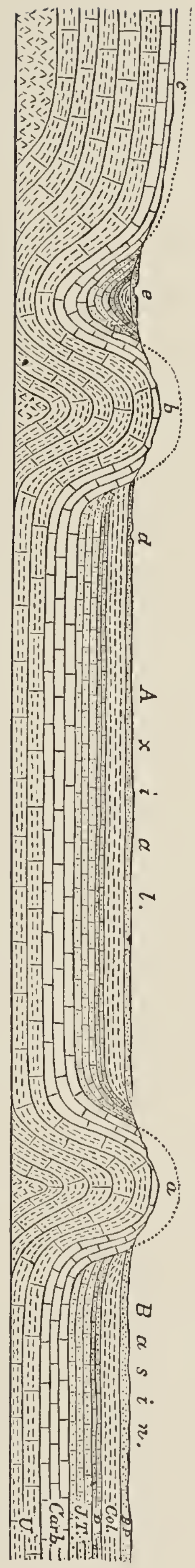


FIG. 61. Section along a part of the inceptive portion of the Uinta axis, showing the Junction and Yampa Mountain upthrusts.

*a*, Yampa Mountain; *b*, Junction Mountain; *c*, Eastern end of the Uinta Range; *d*, Yampa River, before entering Junction Mountain; *e*, Snake River; U, Uinta Sandstone; Carb., Carboniferous strata; JT, Jura-Trias; D, Dakota group. Colo., Colorado group; BP, Brown's Park group.

dulled at certain places so that a part of the iron through which it was being forced would drag, and not be sharply severed. Portions of the uplifted strata at the base of both these mountains seem to have thus dragged during their elevation, while other portions were sharply severed as if the displacement had really been done by a huge punch acting from beneath; producing, of course, an ordinary fault there.

Referring to the fact that the two upthrusts have taken place upon the axis of the inceptive portion of Uinta fold, and apparently after that portion had reached its present stage, it is well to turn aside for the moment to notice further certain other phenomena which are correlated with this, and to consider their probable significance. The phenomena referred to indicate that while the displacements now observable in that region were in progress there were many local arrests and accelerations of the elevating movement which produced a final diversity among them that did not exist in their inception. For example, the present structural condition of the Uinta fold seems to warrant the assumption that it was once, along its entire length, in the condition in which the inceptive portion now is, except for the presence of the two upthrusts; furthermore, that these upthrusts, as well as the main portion of the fold, continued their upward progress while what I call the inceptive portion remained as it was when its elevation was arrested.

Again, it may be assumed that the subordinate folds adjacent to the eastern end of the main Uinta fold all had an approximately equal start with the latter, but that the final extent of the upward movement was different in each case. For example, when the Midland fold ceased to rise the elevation of the others continued. Then the rise of Yampa Plateau fold ceased, while that of the great fold continued until its completion. These successive steps are well indicated in the section, Fig. 59.

The elevating force was not only strangely concentrated in the case of the two upthrusts, but it seems to have been applied in an unusual manner, especially when we consider the position of the longer axis of each with relation to that of the other, and also to that of the Uinta fold. It has been mentioned that the direction of the longer axis of the Junction upthrust is northeasterly and southwesterly. Viewing these upthrusts only in relation to the Uinta fold proper, and regarding them as nearly or quite isolated portions of the same, one would naturally expect to find their longer axes coinciding with a line projected from the axis of the main fold, and he would also expect to find the intervening strata along that line to have partaken largely in the upward movement. That is, in view of the simplicity of the main portion of the Uinta fold one might naturally expect to find evidence that the uplifting force which was applied along its entire axis would have acted with approximate uniformity. But the fore-

going statements show that neither of the axes of the two upthrusts coincide with such a line or with each other. Also, that only a slight elevation of the strata has occurred along the inceptive portion of the Uinta fold, as compared with that of the main portion and with the upthrusts.

While the Danforth Hills uplift holds an intermediary relation to both the Uinta and Park ranges, it seems natural to regard the two upthrust mountains as outlying members of the Uinta Range, and there also seems to be no sufficient ground for doubt that both upthrusts were produced as a part of the orogenic movements which resulted in the final completion of the Uinta fold. Still, the relative position and the peculiarities of these upthrusts are such that it is evident they ought to be studied, not with reference to that fold alone, but also with reference to the Park Range of the Rocky Mountain system. Such a study not only reveals the existence of an intimate relationship between the two great ranges, but it discovers evidence that both of them, together with their subordinate folds, their spurs, and the two upthrust mountains, are all the results of one great system of orogenic movements.

A part of the facts showing the relationship of the Uinta to the Park Range has already been mentioned, and in support of this view the following remarks may be added: A large irregular spur of the Park Range, known as the White River Plateau, reaches within the limits of this district. In this plateau, a large part of which is shown on the lower right hand portion of the accompanying map, the Carboniferous rocks are brought to view as they are in the Uinta Range and in the two upthrusts. Along its western base also the same Mesozoic formations which are upturned at the base of the Uinta Mountains are there upturned, and their outcrop thus formed extends far southward along the western flank of the Park Range. The Fox Hills and Laramie strata thus upturned constitute what is known as the Great Hogback.

A part of these formations, less abruptly upturned, may be traced by a broad curve continuously across the intervening space between the two ranges from the western base of the White River Plateau to the southern base of the accessory folds of the Uinta Range. The general trend of these upturned formations approximately corresponds with that of the inceptive portion of the Uinta axis, but it is somewhat modified by the presence of the Danforth Hills uplift. Their dip also corresponds with the comparatively gentle elevation of the inceptive fold, and there is almost nowhere any indication that either the dip or trend has been affected by either of the two upthrusts.

With the two great mountain folds rising by simultaneous stages at right angles with each other and serving as ponderous buttresses on either hand, it is not strange that any elevating force which may

have been exerted along and at either end of the intervening space should have been diversely, if not abnormally applied. The results of this diversity in the application of elevating force are conspicuously seen in the extraordinary cases of its local restriction; in the diverse positions of the resulting subordinate axes, and in the varying heights to which closely adjacent vertical displacements have reached, all of which have been discussed on preceding pages. An explanation of the mode of origin of these phenomena ought doubtless to be sought in connection with studies in dynamic geology, to complete which would lead the investigator far beyond the limits of the district specially considered in this article.

## CANONS TRAVERSING THE UPTHRUSTS AND FOLDS.

The phenomena described on the preceding pages are certainly of great interest, and a part of them are very remarkable; but some of those which are now to be described, and which pertain to the second of the categories mentioned in the opening paragraph of this article, are, if possible, still more remarkable. Those now to be considered have reference to the corrasion of the valleys and cañons of the rivers which traverse the same region, and a part of which cut through the uplifts that have been described.

To most persons it would seem natural to infer that the rivers which traverse a mountain region would flow through the low lands, avoid the mountains, and pass around the end of the ranges rather than through them. This region, however, presents remarkable examples of an entirely different character; that is, the principal rivers here flow in narrow cañons along a part of their course, which they have themselves evidently cut. Not only is the eastern portion of the Uinta Mountain Range traversed in different directions by such cañons, with the rivers at the bottom, but isolated mountains surrounded by low lands are similarly traversed in the same region. Even when taking into consideration the geological structure of a region, it would not seem unnatural to suppose that the rivers would generally be found to run in synclinal valleys between such folds of the strata as may have been elevated in their vicinity. It is true that a river within this region is sometimes found to occupy a synclinal valley for a short distance; but such cases are rare, while we find numerous examples of rivers traversing such elevated folds as have been described. Indeed, these rivers traverse the folds in such directions, and occupy such positions in relation to them, as to show that the folds have exerted little or no appreciable influence on the location of the rivers.[1]

[1] All the various conditions of drainage with its relation to the underlying geological structure, which occur in this region, have been fully described and discussed by Powell in his Exploration of the Cañon of the Colorado, pp. 160 to 166, to which the reader is referred.

The streams which drain this district, as before mentioned, are Green, Yampa, Snake, and White Rivers, the latter traversing only a portion of its southern border. After leaving the foot-hills of the Park Range, White River reaches its confluence with the Green without having cut any important cañons in either the Great Hogback or the Raven Park fold, both of which uplifts it traverses. It has, however, cut some interesting cañons through the Tertiary strata along other portions of its course; but as these are of somewhat different character from those to which I shall especially refer they need not now be discussed.

Snake River, after receiving the waters of its main tributaries from the foot-hills of the Park Range, flows southwestwardly through comparatively open country to its confluence with the Yampa without traversing any conspicuous uplift of the underlying strata in its course. It even passes closely around the northern end of Junction Mountain and reaches its confluence with the Yampa in Lily's Park through the narrow strip of low land (which is a true synclinal valley) between that mountain and the eastern end of the Uinta Range. In short, it follows such a course as those unacquainted with other conditions would naturally expect a river to choose. But in this respect Snake River is really an exception to the general rule which is applicable to the other rivers that traverse this district, as will be seen by the following remarks on the cañons of Green and Yampa Rivers.

It is true that the course of both Green and Yampa Rivers is in large part through open country, or through lands that are not mountainous, where they have had only the later and softer formations through which to cut their way. But while peacefully flowing along such portions of their course they often strangely leave these seemingly favorable positions to traverse mountains or other elevations which in most cases are composed of harder strata than those over which the rivers had previously been flowing. In traversing these mountains also they almost invariably do it by narrow cañons, the walls of which are often nearly or quite perpendicular, and of great height.

### THE UINTA CAÑONS OF GREEN RIVER.

Green River flows southward through the central portion of the Green River Basin, towards the eastern portion of the Uinta Range of mountains which lies directly across the river's course. Upon reaching the foot-hills the river at once passes through them and enters the northern side of the range. Here, after making a sharp bend in what is called Horseshoe Cañon, as if it were about to return upon itself, it sweeps by another bend further into the range and pursues its course for a long distance through deep, narrow cañons. After the river has reached well within the range it turns suddenly eastward, its course now being through Red Cañon, which lies nearly

parallel with the axis of the Uinta fold. From this cañon it emerges into Brown's Park, the low lands of which it traverses for a distance of about 25 miles, its general course there being a little to the south of east. A less distance farther in that direction would have carried it over similar low lands to the eastern terminus of the Uinta Range, around which, and then southward, the low lands continue. Instead of availing itself of this seemingly favorable route to reach the southern side of the Uinta Range, where lies its destined course, the river leaves Brown's Park at the point indicated, and turning suddenly southward it re-enters the Uinta Range by the "Gate of Lodore," which is the northern end of the narrow cañon by which the river traverses the whole width of the Uinta Range. The cañon walls of the Gate of Lodore rise abruptly from the river and from the south side of Brown's Park, where they are more than 2,000 feet in perpendicular height above the river; and some of the higher points near and along the course of the cañon are fully 1,000 feet higher.

After traversing the whole width of the main range, the river emerges into the short, narrow, synclinal valley between Split Mountain and the main range. This valley, as has already been shown, communicates with the low lands which lie toward the south, the direction in which the river finally flows. But instead of pursuing its way by this apparently favorable route the river enters Split Mountain, cutting entirely through it, and leaving its cañon walls of hard rock towering on either hand to the dizzy height of nearly half a mile. Then, and not till then, does the wayward river consent to go on its quiet course through the open country towards its junction with Grand River, where its waters, mingled with those of that river to form the Colorado, flow through still more profound and remarkable cañons beyond.

## YAMPA MOUNTAIN CAÑON.

The course of Green River across the upfolded Uinta Range, which consists there wholly of the hard strata of the Paleozoic formations, when apparently it might so easily have gone around it upon low lands and have made its channel through softer formations, is so remarkable as to arrest the attention of every observer. But the Yampa is perhaps the most remarkable of all the rivers in that region with reference to their seeming disregard of favoring conditions of location. This river rises by numerous tributaries among the mountains of the Park Range, where it has a turbulent course of many miles through rocky defiles and narrow valleys. Then emerging from the foot-hills of the range, it traverses the open country which lies toward the west, its general direction being toward the eastern end of the Uinta Range and along the greater part of the length of Axial Basin. This latter part of its course, being approximately upon the axis of the inceptive portion of the

Uinta fold, Yampa and Junction Mountains lie directly in its way, while around these mountains lie the low lands already described.

Upon reaching Yampa Mountain, the river, in almost seeming wantonness, cuts its way by a short cañon through the hard Paleozoic rocks which form the northern flank of the mountain, making a small bend into its mass, instead of swerving a little in the other direction and passing at its northern side upon the low land there. This cañon, compared with others in that region, is insignificant, for it is very short and its walls are only from 600 to 800 feet in maximum height above the adjacent low lands; but considered in connection with the geological structure beneath, it is very remarkable.

### JUNCTION MOUNTAIN CAÑON.

From Yampa Mountain the river flows quietly over the low lands of Axial Basin to Junction Mountain, which it cuts through in a similar manner. As one stands upon Junction Mountain and looks out over the broad low land which lies adjacent to its northeastern side and is continuous with Axial Basin toward the east and with Brown's Park toward the west, the opportunity seems especially favorable for the Yampa to have reached the further side of Junction Mountain by joining Snake River near the northern end of the mountain. Indeed, for more than half its course after leaving Yampa Mountain the river trends in that direction as if it were destined to go there; but instead of doing so, it makes a distinct bend southwestward, goes direct to Junction Mountain and cuts off its southern end, as it had already cut off the northern end of Yampa Mountain. The strata of hard rock, which are upturned like a broken dam at the foot of the steep mountain side, constitute no impediment to the course of the river, and without swerving to the right or left it enters the mountain and traverses it by a narrow cañon, the almost perpendicular walls of which reach a maximum height of from 1,000 to 1,200 feet above the low land at either end of the cañon.

### YAMPA CAÑON.

After having traversed Junction Mountain, the river has a peaceful course of eight or ten miles through Lily's Park, which is merely a broadening of the valley, where it receives the waters of Snake River. Then, instead of joining Green River by way of the low land at either the northern or southern side of the Uinta Range, it boldly enters its eastern end, crossing the upturned strata there as it had done in the former cases. From here the remainder of the river's course is through a narrow cañon, which, for a large part of its length, is fully 1,200 feet deep, and which joins the cañon of Green River before the latter emerges from the southern side of the range.

The distance from end to end of Yampa Cañon, in a straight line, is about twenty miles. While it meanders to some extent, its general course is direct, and coincides approximately with the axis of the Uinta fold. That is, the narrow cañon has been cut perpendicularly into, and mainly along the strike of, the hard Carboniferous strata, where they have their southerly dip in the southern flank of that fold. In short, the position and direction of the river are such with relation to the dip and trend of the strata there that no indication is apparent that the latter have had any influence in determining the former.

### CONCLUDING REMARKS.

If the phenomena relating to the river cañons of this district which have just been described were considered without reference to, or any knowledge of, a geological history of the region in which they occur, they would be wholly inexplicable; but considered with reference to that history, their origin is easily explainable. And yet, with all the relevant facts in mind, even he who is accustomed to weigh and consider such evidence is often amazed at the results which have been produced by the forces which are and have always been in constant operation upon the face of the earth.

The following summary statement of the origin of these phenomena is given in a few words, but a careful examination of Powell's elaborate statement of the subject (op. cit.), should not be omitted.[1] The rivers of the region occupied the surface before it was elevated to any considerable height above the level of the sea, and before the region was greatly disturbed by orogenic movements. When the uplifts were formed in which the mountains originated, the rivers refused to yield "the right of way."[2] That is, the rivers were

[1] This subject is also well stated by Dutton in the Second Ann. Rep. of the Director of the U. S. Geol. Survey, pp. 60–63.

[2] The theory is entertained by some geologists that the later formations completely mantled the whole region after the great displacements which have been described occurred, and after resulting mountains and other great topographic features were produced. Further, that the present drainage system was established upon the surface of those later formations, and that the streams have dropped to their present levels as the surface of the region gradually became degraded by erosion. Such a theory requires—

(1) That the present drainage system of which the Colorado is the principal channel was established after the close of the Tertiary period.

(2) That this system was established upon a land surface the lower portions of which were then at an elevation little if any less than 10,000 feet above the level of the sea, a large part of it at a still greater elevation.

(3) That to give the requisite amount of drainage water to produce the vast erosion and corrasion which have taken place there, the geographical extent of that greatly elevated region must have been quite equal to that which is now drained by Green River and its tributaries.

The possibility that such conditions could have existed seems inadmissable.

established in a large, comparatively plain region, which they drained, their location having been determined by conditions then prevailing. Subsequently, movements of the earth's crust took place in the same region, resulting in broad elevations and in elongate folds and locally restricted uplifts, the material of which, after great erosion, became respectively the high plateaus, mountain ranges, and isolated mountains or mountain clusters which now exist. When the later part of the elevation of the great Plateau Province took place its pre-existing drainage system was necessarily raised with it to some extent, so that their river beds are now at a higher level above the sea than they originally were. But this elevation of the river beds has been little as compared with that of the present land surface, and especially so if compared with the amount of vertical displacement that has taken place there since the rivers were first established, because the rivers have maintained a comparatively low level for their beds by cutting deep cañons in the rising land.

When a fold like that of the Uinta Range, for example, began its elevation across or along the course of one of these rivers, the corrasive action of the latter was immediately exerted upon the threatened obstruction, and overcame it regardless of the hardness of the uplifted rock, and this action did not cease or fail in its effect as long as the elevation continued. This corrasive action of rivers is, indeed, very slow; so also has been the movement of elevation, the one having balanced the other even through thousands of feet of vertical elevation of the underlying rocks. In view of the stupendous effects of the action of these two forces which may be witnessed in the cañons of the region here discussed, and in the still grander cañons of the Colorado, one becomes impressed with the immensity of the results which may be accomplished by slowly acting forces through long periods of time.

Not only were the rivers not checked in their flow when mountain folds were elevated athwart their course, but they refused to be thrust aside by such folds as may have been raised either directly or partially beneath them with the direction of their axes coinciding more or less nearly with that of the river's course. The longer cañon of Yampa River, upon the southern flank of the Uinta fold, and Red Cañon of Green River, upon its northern flank, are examples of such cañons as have been cut in a direction approximately parallel with the axis of a fold which has been elevated from beneath them, while the direction of Lodore Cañon, of the latter river, is transverse to the axis of the fold.

But, since these longer cañons traverse broad folds and elevated areas, it may be suggested that the rivers which produced them were less liable to be swerved from their original courses by the vertical movement which took place beneath them than they would be in the

case of the rising of narrow folds and of such upthrusts as have been described. But the facts already presented show that the elevation of not only the narrowest folds, but even that of the two upthrusts which have been described did not cause the rivers under which their elevation began to swerve from their original courses as the elevation progressed, to the extent of more than a few rods. This fact is exemplified in Split Mountain, where Green River cuts a short, deep cañon through that prominent spur of Yampa Plateau; but it is more conspicuously shown where Yampa River traverses both the Junction and Yampa Mountain upthrusts.

I am sure that the phenomena described on the foregoing pages merit the statement made in the opening paragraphs of this article that they possess peculiar interest; but, among them all, none are more likely to permanently impress the reader than those which are connected with the two upthrusts and the short cañons which traverse them.

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